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FOREIGN TECHNOLOGY DIVISION

ANTITANK ROCKET MISSLES

By

B. I. Yevdokimov

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EDITED MACHINE TRANSLATION

ANTITANK ROCKET MISSLES

By: B. I. Yevdokimov

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B. I. Yevdokimov

PROTIVOTANKOVOYE REAKTIVNOYE ORUZHIYE

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ANTITANK ROCKET MISSILES

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ABSTRACT: This pamphlet gives a popular treatment of the problems of design and combat application of antitank guided missiles [ATGM] (ПТУРС). It relates the reasons that prompted the development of these missiles and the classification of ATGM's according to the most important criteria. After an acquaintance with the general concept of an ATGM, a more detailed account is given of the basic principles of designing the individual components of the ATGM (rocket engines, airframes, and so forth). For an understanding of the principles of action of the individual ATGM components, brief information is given from aerodynamics, the theory of gyroscopes, and electronics. The pamphlet discusses the methods of firing antitank guided missiles and the procedures of firing instruction. Problems concerning the combat application of ATGM for various types of troops and for the most important forms of combat are outlined. Brief performance characteristics of contemporary ATGM's are given and the means for their further development are discussed. Futhermore, a brief description of contemporary unguided antitank rocket weapons is presented. The pamphlet was written on the basis of materials of the foreign press and does not pretend to give an exhausting account of all the problems connected with the fundamentals of design and the principles of combat utilization of ATGM's. The pamphlet is intended for an extremely wide range of military and civilian readers who are interested in new military equipment and its combat application. English translation: 45 figures; 86 pages.

TABLE OF CONTENTS

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

ANTITANK ROCKET WEAPONS

B. I. Yevdokimov

This pamphlet gives a popular treatment of the problems of design and combat application of antitank guided missiles [ATGM] (ПТУРС).

It relates the reasons that prompted the development of these missiles and the classification of ATGM's according to the most important criteria.

After an acquaintance with the general concept of an ATGM, a more detailed account is given of the basic principles of designing the individual components of an ATGM (rocket engines, airframes, and so forth). For an understanding of the principles of action of the individual ATGM components, brief information is given from aerodynamics, the theory of gyroscopes, and electronics.

The pamphlet discusses the methods of firing antitank guided missiles and the procedures of firing instruction. Problems concerning the combat application of ATGM for various types of troops and for the most important forms of combat are outlined.

Brief performance characteristics of contemporary ATGM's are given and the means for their further development are discussed. Furthermore, a brief description of contemporary unguided antitank rocket weapons is presented.

The pamphlet was written on the basis of materials of the foreign press and does not pretend to give an exhausting account of all the problems connected with the fundamentals of design and the principles of combat utilization of ATGM's.

The pamphlet is intended for an extremely wide range of military and civilian readers who are interested in new military equipment and its combat application.

INTRODUCTION

In recent years, more and more attention has been given abroad to the improvement of tanks and the means of defense against them.

In the opinion of foreign specialists, the role of tanks in a future war will significantly increase. Inasmuch as, under conditions of thermonuclear war, tanks possess such valuable qualities as good protection of the mechanisms and the crew from shock waves, flash, and radiation, they are better than any other arm of the service, and are able to use the effects of the nuclear attacks of their own forces on the enemy. Furthermore, it is considered abroad that tanks are also effective antitank weapons.

Considering the possibility of the application of tactical nuclear weapons, western specialists consider that the main task of tanks in an offensive operation will be to break through the enemy defense and effect a swift victory in his depth.

The main defensive objective of tanks, in the opinion of foreign military specialists, will be the infliction of counterattacks. They will be used as antitank weapons in defensive operations only in exceptional cases.

In connection with the fact that military specialists abroad attach such a large value to the role of tanks in future war, all the capitalistic countries are continuing to improve tanks in the direction of strengthening their armor protection, increasing maneuverability, and increasing the power of tank guns.

The first tanks had limited mobility, and their armor was relatively thin; therefore, they could be successfully defeated by means of conventional artillery and grenade clusters. In time, tank armor became thicker, their speed and maneuverability increased, and their armament became more powerful. Tanks were turned into threatening high-speed machines, armed with powerful guns, and capable

of long-range fire.

Antitank guns and their ammunition were simultaneously improved. During the Second World War, antitank guns reliably protected the infantry from enemy tanks.

In connection with the main combat assignment of antitank guns (the demobiliza-tion of tanks), they are presented with special requirements.

First of all, they have to be light, so that they can be rolled manually behind advancing infantry, they must be able to open fire on tanks quickly, and react to the movements of tanks which, owing to their mobility, may unexpectedly appear from any direction.

Antitank guns must have the required point-blank range (Fig. 1), i.e., the range at which the trajectory height does not exceed the height of the target (tank). Furthermore, they must possess a rapid-firing capability. A tank should be directly hit in one or two shots, since a tank moves at a high speed. Therefore, tanks are fired upon by direct laying from point-blank range. Consequently, an antitank gun should have a low trajectory. Finally, antitank weapons must possess a high armor-piercing capability and a close shooting pattern.

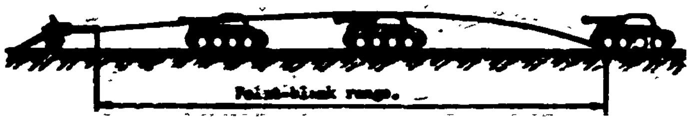


Fig. 1. Point-blank range.

Antitank weapons were improved in accordance with these requirements.

However, an increase in power and an increase of point-blank range are connected with an increase of caliber and initial velocity, which inevitably leads to an increase in the weight of the weapon and lowers its maneuverability. Therefore, the designers continuously worked on the creation of weapons which would best correspond to these contradictory requirements.

Of large value in the history of the development of antitank weapons was the invention of hollow shaped-charge projectiles which do not require high velocities for piercing armor. This made it possible, without increasing the initial velocity of the weapons, to increase the armor-piercing capability of the shells. However, in spite of this, the initial velocity continued to be increased in order to increase the point-blank range and the hit probability.

The antitank weapons of the countries that fought in the Second World War weighed from 1 to 1.5 tons and could pierce armor up to 200 mm thick at a point-blank

range of up to 1000 meters.

During the Second World War, new ways of developing antitank weapons were sought. The search ended with the creation of a principally new form of weapon, i.e., the antitank guided missile [ATGM] (ПТУРС).

The development of these missiles began in Germany in 1942-1943. However, the Fascist German Army was defeated before these missiles went into the field. After the war, the development of new forms of missiles continued in all of the larger capitalistic countries, and now they have created a whole series of antitank missiles of the most diverse designs.

However, all of these missiles presently possess a number of shortcomings, as a result of which, in the opinion of foreign specialists, it is necessary to arm the infantry with light-weight, close-range, antitank weapons. Therefore, along with antitank guided missiles, a number of foreign armies also have unguided antitank rocket weapons.

1. GENERAL INFORMATION CONCERNING THE DESIGN OF ATGM's AND THEIR CLASSIFICATION

During the flight of an artillery shell, it is acted upon by basically two forces: gravity and air resistance. Due to the action of these forces, the flight trajectory of the shell constitutes a curve. It is clear from Fig. 1 that if it would be possible to straighten out at least the last phase of the trajectory, the shell would fly considerably further. The last phase of the shell's trajectory can be straightened out only when a method is found for balancing the action of gravity for a definite length of time. Then an antitank missile will be able to fly on a straight line further than a conventional missile.

It seems that there is such a method, and it can be observed very frequently, e.g., during the flight of aircraft. Furthermore, there are rockets which can fly on a course that has been shown to them beforehand. Consequently, it is fully possible to create an antitank missile with a straightened trajectory. This missile should have small dimensions, be light, convenient for transporting and maneuvering in the battlefield, have the necessary radius of action, and high accuracy of firing.

Such missiles are now available in many countries of the world. The antitank missile, which is constructed like an aircraft, has wings that create lift during motion, and balance the gravity force. Antitank missiles are equipped with rocket engines which, first of all, make it possible to construct a very light launcher and, secondly, to surmount the action of air resistance during the operation of the rocket engine.

So that the missile does not deviate from its assigned direction due to inaccuracies in its manufacture and the influence of gusts of wind, and also for taking into account tank maneuvers and the possibility of correcting sighting errors, it is equipped with special instruments that make it possible to control it

at long range.

Contemporary antitank guided missiles (for instance, missiles with solid-propellant engines) consist of the following basic components or units (Fig. 2): warhead 1, rocket engine 2, airframe 3, stabilizing elements 4, instruments of guidance and control system 5, and ailerons 6.

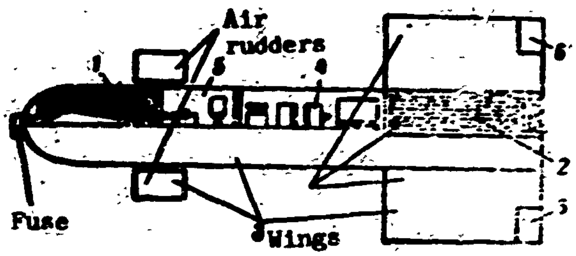


Fig. 2. Diagram of ATGM with SRE:
1 — warhead; 2 — rocket engine;
3 — airframe; 4 — stabilizing elements;
5 — control system; 6 — ailerons.

The warhead consists of an explosive charge, a detonator, a detonating cap, and a fuse. The explosive charge is hollow and is intended for the immediate destruction of tank armor. A hollow-type explosive charge makes it possible for the missile to pierce tank of armor at a low velocity.

Most antitank missiles have two rocket engines. One of them is called the booster, and the second is known as the sustainer. The booster accelerates the missile to the necessary velocity, after which its ceases operation. The sustainer either maintains a constant velocity, or increases it somewhat, and operates until the missile hits the target. The booster operates for 0.5 to 3 seconds; the sustainer operates for a few seconds, depending upon flying range (this pertains to missiles whose velocity of flight is 100 to 200 m/sec). The sustainer of the majority of missiles is designed so that its thrust is approximately equal to the air resistance. The thrust of certain missiles is considerably greater than the air resistance (for instance, that of the French missile SS-11).

Antitank missiles employ solid-propellant rocket engines [SRE] (ПРД), air-breathing jet engines [AJE] (ВРД) and liquid-propellant rocket engines [LRE] (ЖРД).

The airframe consists of a body (it is also the body of the missile), wings, and rudders or other controls. It connects all the missile units and creates the controlling forces that are necessary for guiding the missile to the target.

The wings can be plane and annular.

Aerodynamic and gas-dynamic rudders are employed. The aerodynamic rudders can be made in the form of deflecting plates or in the form of spoilers. The missile can also be controlled by varying the direction of action of the reaction force of the engine.

The fins are designed so that the missile flies correctly, i.e., does not bank and turn about.

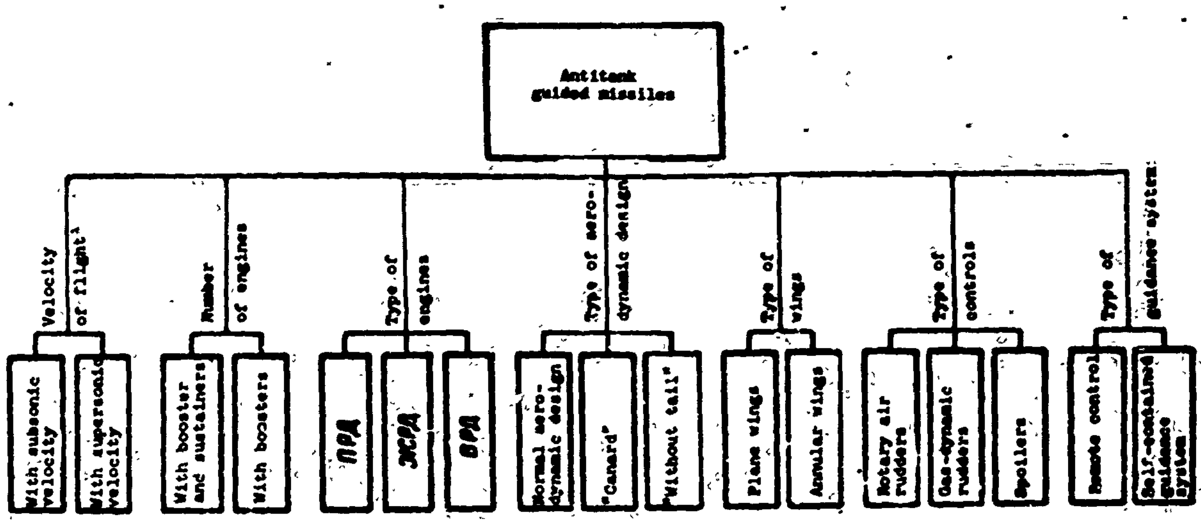
The instruments of the guidance and control system permit remote control of the missile.

The missiles of the capitalistic countries mainly employ two guidance and control systems: wire and radio. They are called remote-control systems.

An antitank missile can also be guided and controlled by means of a predetermined program. During the flight of the missile, its program can no longer be changed. This type of control system is said to be self-contained.

Guided antitank missiles are very diverse with regard to design. Therefore, for convenience of study, they are subdivided into groups according to the character of the design of individual units and certain other criteria. The classification of foreign antitank missiles according to the basic criteria is shown in Fig. 3.

After an acquaintance with the general construction of antitank guided missiles and their classification, we shall go on to a more detailed consideration of their design and principle of action.



[1]The speed of sound at 16°C is approximately equal to 340 m/sec.

Fig. 3. Classification of foreign ATGM's.

2. ATGM WARHEAD

As it is known, the warhead of a missile consists of an explosive charge, a detonator, a detonating cap, and a fuse; the explosive charge, as a rule, is shaped.

The explosive charge directly destroys armor. And what is the action of the detonator and the fuse?

An explosive charge is usually made from a powerful explosive that is not very sensitive to external influences (shocks, impressions, fire). It explodes when another, more sensitive explosive is set off with it; the quantity of this explosive can be significantly smaller. This phenomenon is called detonation. Therefore, the warhead, in addition to containing an explosive charge, also has a certain quantity of another explosive, which is called the detonator.

The fuse sets off the detonator. It contains a small quantity of sensitive explosive. This explosive is placed in a special box which is called a flash igniter. However, the flash igniter cannot set off the detonator. The detonating cap is used for this purpose. It contains enough explosive to set off the detonator. The detonating cap is set off by the explosion of the flash igniter and it yields a quite powerful impulse, which sets off the detonator. The explosion of the detonator sets off the explosive charge of the missile. Explosion of the flash igniter occurs when the missile's nose strikes against the tank armor. Besides the type described, there exist other kinds of fuses.

We shall now explain the arrangement and action of a hollow shaped-charge and what the hollow shaped-charge effect is.

The hollow shaped-charge effect was known long ago. It consists of the following: it was noted that when charges were set off which contained depressions,

the hole that was made was larger than when charges not containing depressions were set off.

However, only in beginning of the Second World War was this effect, which was essentially modified, widely used for military purposes. In the first years of the war, almost simultaneously, all armies began to employ new combat weapons that utilized the hollow shaped-charge effect. It was established that if a depression is made in a charge in the shape of a cone and the walls of this depression are faced with a thin metallic shell, the projectile will be able to pierce armored plates, concrete walls, etc., better than a conventional charge of the same weight.

A diagram of the arrangement and action of a hollow shaped-charge is shown in Fig. 4. When the charge explodes, the blast wave moves along the charge. After reaching the top of the thin-walled metallic cone, the blast wave creates a very high pressure on the external side of the cone. Under the action of this pressure, the walls of the cone are compressed and, at a high speed, they go inside, almost perpendicular to the surface of the cone. A phenomenon occurs which is analogous to the converging of solar rags in the focus of a convex lens.

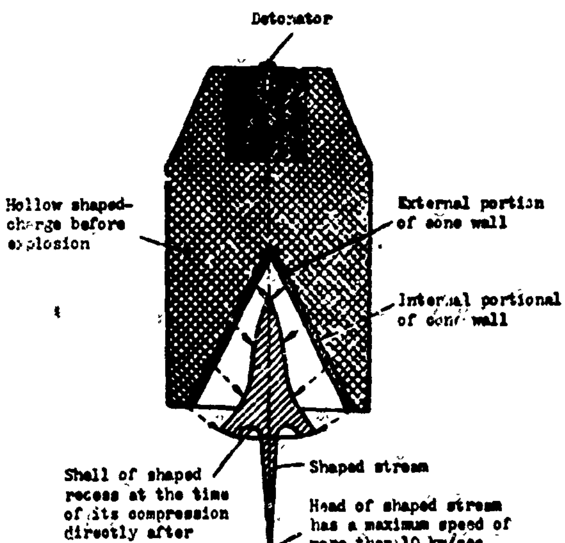


Fig. 4. The hollow shaped-charge effect.

The compressed shell moves in the form of a stream whose tip is directed along the axis of the projectile. The metal from the internal portion of the shell wall moves at very high speeds (attaining 10,000 m/sec and above), and from the external portion of the shell wall at comparatively low speeds (to 1000 m/sec). Due to this difference in speeds, the metal expands into a shaped stream whose head moves at a tremendous speed. The formation of deep holes in armor occurs under the action of the shaped stream, whose pressure reaches 400,000 at, and the action is similar to the action of a powerful jet of water from a fire pump, but, of course, more powerful. This powerful stream of metal strikes the armor with a tremendous force and pierces it, strongly heating the armor at the point of impact, so that the edges

of the hole are fused. The impression is created that the armor is not pierced, but is burned-through; therefore, the first hollow-charge projectiles were called armor-burning missiles. Now it is clear that this name reflects only the external sign of the action of the missiles, and not the physical essence, i.e., the severe impact of the stream against the armor. Neither the strength of the missile body, nor the speed of its flight have the value that they have for conventional armor-piercing missiles that pierce armor with the body of the missile, which is flying at a high speed.

3. ATGM ROCKET ENGINE

The application of rocket engines in antitank missiles made it possible to change from guns with barrels to launchers which are many times lighter than guns. If a contemporary antitank gun weighs about 1.5 tons, an antitank guided missile together with launcher may weigh a total of 50-60 kilograms and even less.

Let us briefly consider the principle of jet propulsion[1].

According to Newton's third law, the action of two bodies on one another is always equal and in the opposite directions.

The action of this law may be observed in daily life. For instance, a rower who removes a certain mass of water in one direction with his oars, forces the boat to move in other direction. Approximately the same thing occurs in the motion of a ship or a propeller-driven aircraft.

In all these cases we are concerned with engines of indirect reaction, which do not directly interact with the surrounding external medium. Engines of indirect reaction influence the external medium with the help of a special intermediary, i.e., an impeller. For a rower, who is the engine, the impeller is the oar; for a ship and aircraft, it is the screw or propeller; for a streetcar and automobile, it is the wheel.

A jet engine does not require any intermediaries, i.e., impellers; therefore it is called a direct-reaction engine.

The principle of operation of a jet engine is simple. Anyone who has fired a gun or rifle has experienced the recoil force. During the action of firing, the

[1]A more detailed presentation of the principle of reactive motion is given in the pamphlet of this series entitled "Physical Fundamentals of Rocket Flight," by L. A. Dmitriyevskiy and V. N. Koshevoy.

gases that have formed in the barrel as a result of combustion of the powder press is uniformly on all sides: on the barrel walls, the bottom of the case, and also on the bottom of the bullet. The pressure forces on the barrel walls are mutually balanced. The pressure on the bottom of the bullet makes it leave the barrel in a forward direction; the pressure on the bottom of the case forces the gun backward by the action of the gases, thus striking the shoulder. The pressure on the bottom of the case is the cause of recoil. In artillery pieces the recoil force is so great that special counter-recoil devices are employed to compensate it. The phenomenon of recoil is an example of jet propulsion. The source of motion in a jet engine is the reaction or recoil of a gas stream.

Let us imagine a closed vessel (Fig. 5) which contains a compressed gas. The gas pressure in the vessel acts in all directions with an identical force (Fig. 5a). It is uniformly distributed on all walls of the vessel, which in this case remains motionless. If, however, we remove one wall (end), the compressed gas, which then expands, will flow from the vessel (Fig. 5b). The pressure on the end walls will not be balanced. If the vessel is not secured, it will start to move in the opposite direction of the gas flow. The greater the gas pressure, the higher the velocity of its flow, and an even greater force will move the vessel. The main part of any jet engine is the combustion chamber. In it there occurs the burning of fuel, as a result of which gases and heat are intensely given off. The strongly heated gases, trying to expand, flow through a nozzle, simultaneously forcing the combustion chamber and the entire rocket together with it to move in the direction opposite the flow of the powder gases. This force is called the reactive force, or thrust, of the engine.

Antitank missiles have three types of engines: solid-propellant rocket engines [SRE] (ПРД), liquid-propellant rocket engine [LRE] (ЖРД), and air-breathing jet engine [AJE] (ВРД).

SRE's and LRE's have a propellant that is made up of a fuel and an oxidant. The air-breathing jet engine contains a fuel only, while the oxidant (oxygen) is taken from the atmosphere.

Let us familiarize ourselves with the principle of action and design of the enumerated engines.

SRE. Most foreign antitank missiles (SS-10, SS-11, and others) are equipped with solid-propellant rocket engines. Their design is rather simple An SRE consists

of a combustion chamber, which is made in the shape of a tube, and a nozzle. The nozzle is a short conical tube; its narrow end is connected to the combustion chamber (Fig. 6). The propellant that is used is a special smokeless powder which is pressed in the shape of one or several cylindrical grains. The shape of one cross-section of the grains can be extremely diverse: in the shape of a ring, star-shaped, and so forth. The shape and dimensions of the grains, and also their location in the chamber, are selected depending upon the necessary magnitudes of thrust and the burning time. The powder burns in the SRE for several seconds or even fractions of a second.

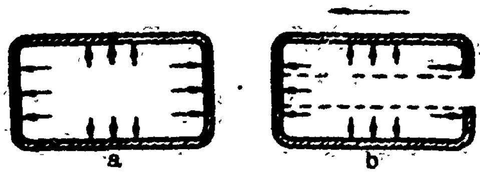


Fig. 5. Formation of a reactive force.

A powder grain is ignited by a special igniter that consists of black powder. The igniter is set off by an electric firing mechanism.

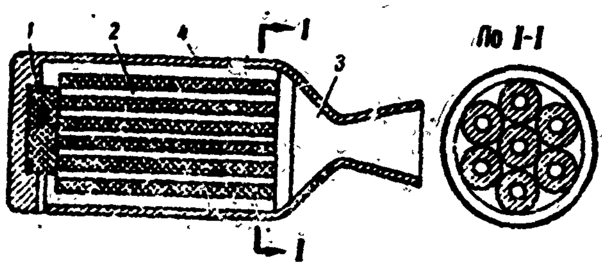


Fig. 6. Diagram of an SRE: 1 — igniter; 2 — powder grains; 3 — nozzle; 4 — combustion chamber housing.

LRE. The theory of liquid rocket engines and their first designs were developed by the famous Russian scientist K. E. Tsiolkovsky (1857-1935). The design of the LRE is more intricate than that of the SRE. Figure 7 shows a schematic diagram of an LRE.

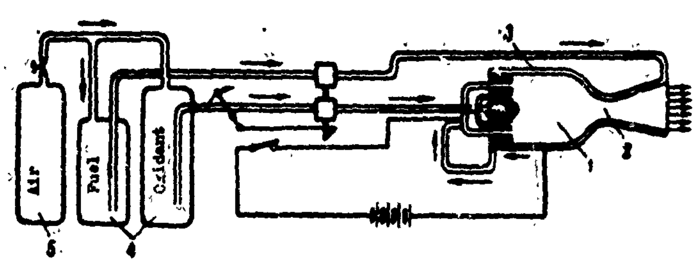


Fig. 7. Diagram of LRE with cylinder feed: 1 — combustion chamber; 2 — nozzle; 3 — engine head; 4 — fuel tanks; 5 — compressed-air cylinder.

The main part of an LRE is the combustion chamber 1 with head 3 and nozzle 2. The head contains injectors through which the liquid propellant is introduced into

the combustion chamber and atomized in it. The propellant is fed from tanks 4 into the combustion chamber under the pressure of the compressed gas that is in the cylinders 5. The pressure in the combustion chamber is several atmospheres. For normal feed of the propellant from the tanks into the combustion chamber, the pressure of the gases that displace this propellant should be several atmospheres higher than the pressure in the chamber.

Alcohol, kerosense, gas oil, or aniline are employed as fuels: oxygen, nitric acid, or hydrogen peroxide is used as the oxidant. During operation of the LRE, the fuel and oxidant are displaced by the compressed gases into the combustion chamber. The combustion products — intensely heated gases — flow outside through the nozzle.

AJE[1]. There exist several types of air-breathing jet engines. The "Lutin" antitank missile employs a ramjet engine [RJE] (ПВРД). A schematic diagram of RJE is shown in Fig. 8. As can be seen from the figure, it is very simple. The RJE housing 1 is a streamlined body with a channel through which the air flow moves. The fuel in these engines is injected by fuel injectors 2 into the through channel, which simultaneously serves as the combustion chamber; the fuel burns in the oxygen which comes from the atmosphere together with the air 3. Engine operation requires that the pressure in the chamber be greater than atmospheric pressure. Such pressure is created in the chamber during flight due to the impact pressure of the air. The temperature in RJE combustion chambers attains 2000-2500° C. In distinction from solid and liquid rocket engines, the RJE combustion chamber does not have a bottom.

How does thrust originate in this engine? Jet thrust in an RJE appears due to gas pressure on the internal walls of the engine. In this engine, the pressure along the surface of the diffuser, as can be seen from Fig. 8, is not distributed in the same manner as along the walls of the nozzle, and its magnitude is much higher. Furthermore, the area of the outlet section of the nozzle is considerably larger than the area of the inlet section of the diffuser, as a result of which there will form a reactive force. Engine thrust is formed due to the composition of all the enumerated pressure forces. This type of air-breathing jet engine is said to be

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[1]A more detailed account of the design and principle of action of the AJE is given in the pamphlet of this series entitled "Air-Breathing Jet Engines," by G. Yu. Mazing.

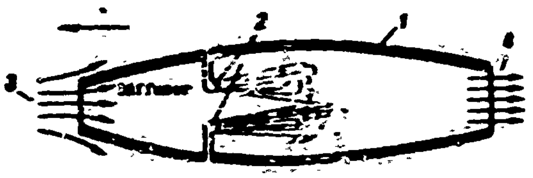

Fig. 8. Diagram of an RJE: 1 — engine housing; 2 — fuel injectors; 3 — air entering engine; 4 — gases flowing from nozzle.

direct-flow because the air in it passes freely into the channel through the whole engine in a direct flow, never turning or encountering any mechanisms on its way. The air only oxidizes the fuel and, in the form of a heated gas 4, it flows from the nozzle. In spite of the simplicity of design of this engine, which is a very important advantage, the RJE has a very significant shortcoming. A ramjet engine does not create thrust during launching since air pressure is created in it only during flight; therefore, it can be used only as a sustainer.

It has already been noted that most antitank guided missiles have two engines: a booster and a sustainer. As a rule, the booster is not separated in flight. The flight of subsonic antitank missiles at a range of 2-3 km continues for 20-30 sec. The booster then operates for only 0.5-3 sec, and the sustainer operates for the rest of the time.

Rocket engines are placed in the body of the airframe.

4. ANTITANK GUIDED MISSILES ATGM AIRFRAME

We know that anybody that is moving in air experiences a resistance to its motion which is called drag. Air resistance is experienced in all moving bodies (pedestrians, motor vehicles, trains, aircraft, missiles, rockets, etc.). Drag renders a harmful braking action and attempts have been made to decrease it by giving appropriate shapes to the automobile, aircraft, missile, rocket, and other bodies that move at high velocity. The higher the velocity the greater the requirements presented to the shape, since air resistance increases with the increase of velocity.

However, flights without air would be impossible. The useful action of air consists in creating lift, owing to which contemporary aircraft raise several tons of cargo to high altitudes.

Let us explain what occurs during the motion of a missile in the air and how lift takes place[1].

The main cause of the appearance of air resistance to the motion of a body is the pressure that arises due to the fact that any body that is moving in an air medium experiences continuous shocks of extremely small particles of incident air.

Another cause of the appearance of air resistance is the friction of the body's surface against these particles.

Air is a mixture of gases and water vapor. It possesses the property of viscosity, which means the ability of a liquid or a gas to resist the movement of one layer with respect to another. When a mass of air moves, the velocities of

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[1]A more detailed account of the aerodynamics of rockets is presented in the pamphlet of this series entitled "Aerodynamics of Rockets," by S. P. Kislev.

its particles are unequal in different layers. Separate layers that move at various velocities appear to slide along one another. In this motion, the layers act upon one another with a force called the force of internal friction, or the force of viscosity. During one motion of a body, the air particles become entangled "rub together" behind its surface. These particles "adhere" to the surface of the body. Due to the viscosity of the air, they in turn attract the particles of the adjacent layers of air. For moving the captured air particles, the moving body expends part of its kinetic energy. It has been proven that in the absence of viscosity the action of a gas or a liquid on a body moving in it would lead only to forces directed perpendicular to its surface, i.e., to so-called normal forces. Inviscid gases and liquids that are separated by a body create an excess of pressure in its forward section, which is compensated by an excess of pressure in the tail section that appears due to the joining of streams while flowing around the body. However, this is valid only if the body moves at a subsonic velocity and there is no separation of the flow.

In reality, even in a complete flow around asymmetric body (Fig. 9a), it experiences resistance to its motion. This resistance is the result of the action of viscosity forces.

When a body is enveloped by a flow with its separation from the surface (an asymmetric body) there will form a vortex wake, the air motion in which is also determined by the forces of viscosity (Fig. 9b).

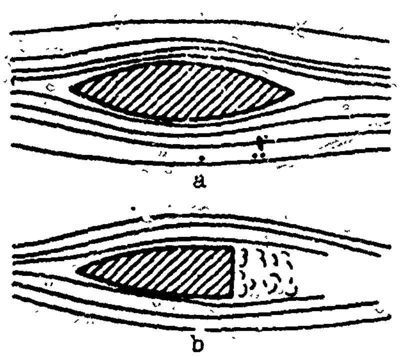

Fig. 9. Flow of air around a symmetric and an asymmetric body.

As a result of the separation of flow and the vortex formation, there appears a region of lowered pressures. The body experiences additional resistance due to the pressure difference on the nose and tail. With a slow decrease of the cross-section, there can be no separation of flow from the surface of the body; there will also be no vortices in this case.

For studying in the peculiarities of flow around bodies of various shape, there exist special devices, e.g., wind tunnels. With the help of these tunnels, the forces acting on a body when it is encompassed by a flow of air are determined, and the pattern of flow is observed. As a result of testing bodies of various shapes in wind tunnels, the most advantageous body shapes were determined from the point

of view of decreasing resistance. It turned out that the least amount of air resistance is experienced by bodies in the shape of a drop. Vortices almost do not form when such a body is enveloped by a flow.

Theoretically, by means of numerous experiments in wind tunnels and other experimental investigations, it was established that the resistance of air to a body moving in it depends on the area of the maximum cross-section of the body, the velocity, the shape of the body, and the density and temperature of the air. Furthermore, air resistance depends on the condition of the body's surface. Air resistance increases with the increase of velocity and surface roughness of the body.

During the study of the motion of bodies in air, it is necessary to consider velocity. If this velocity is considerably less than the velocity of sound in air, it renders a comparatively small influence on the resistance to the moving body. If, however, the velocity of the body exceeds the velocity of propagation of sound, the air exerts a considerably greater resistance to the moving body.

The velocity of sound is the velocity of propagation small perturbations in air. It is not a question here of the presence of sound vibrations in the air (for instance, playing musical instruments, firing artillery pieces, and so forth), but a question of the velocity of their propagation in air regardless if they are present at a given moment or not.

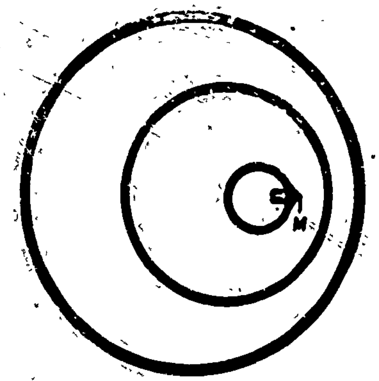

Fig. 10. Formation of spherical waves at subsonic velocity.

For a clarification of the difference in phenomena occurring during the motion of a body with subsonic and supersonic velocity, we shall consider, in a flow of air that is moving with some velocity V, a fired point M (Fig. 10), near which there will form a slight local concentration. This local concentration generates a spherical wave at each given moment. Its center passes together with the flow at velocity V, and its velocity of propagation is equal to the velocity of sound a.

If V is less than a, the system of waves that appear in the time intervals t, 2t, and 3t to a given moment will have the character shown in Fig. 10. As can be seen from this figure, the perturbation is propagated nonuniformly, but in all directions. In other words, during motion with subsonic velocity, the body pushes the air particles that are in front of it. These thrusts

are transmitted from some particles to others with the velocity of sound. The forward flying particles of air, as if beforehand, are "warned" about the motion of the body by a signal in the form of sound waves. The "warned" particles part and flow around the body, making a path around it. The body, while advancing forward, experiences comparatively little resistance.

Another picture is obtained during the motion of a body with supersonic velocity, i.e., when V is greater than a. In this case, spherical waves are inscribed into a certain conical surface whose vertex coincides with the position of the source of perturbation, i.e., fixed point M (Fig. 11). Intense shock waves, which are called by bow waves, are then created. The formation of these waves uses up the kinetic energy of the missile. The decrease of kinetic energy is expressed in the drop of velocity of the missile and in the appearance of an additional resisting force which is called wave resistance. An air stream appears to strike against the body. At the point of impact there appears a shock wave. The pressure and temperature inside this shock wave increase very sharply, i.e., abruptly. Namely in this zone of concentrated air, the energy of motion of the body turns into heat, whereupon the pressure strongly increases. Thus, the additional resistance in this case is a direct result of the transformation of mechanical energy into heat. In shock waves we can distinguish the motion with supersonic velocity from the motion with subsonic velocity. Wave resistance amounts to 50% and more of the total resistance of the missile.

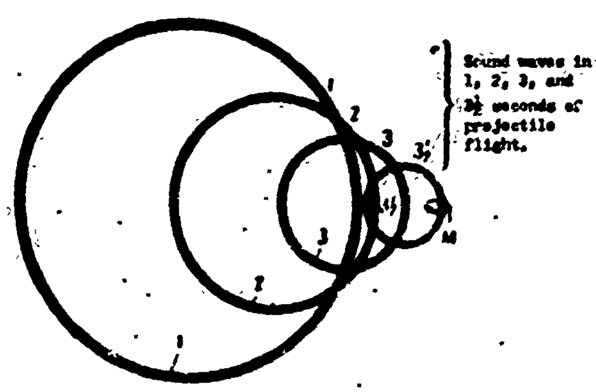

Fig. 11. Formation of spherical waves at supersonic velocity.

The main requirement of aerodynamics presented to the body and wings of any missile that is intended for subsonic flight is the smoothness of the air flow around the body for decreasing the burbling zone, i.e., the aerodynamic wake. Upon fulfillment of this requirement, the air resistance leads almost exclusively to frictional

resistance, the magnitude of which depends insignificantly on the shape of the body.

This is not sufficient for supersonic missiles, inasmuch as during their flight a large role is played by the wave resistance, whose magnitude depends on the shape of the nose of the missile body and the shape of the lifting surfaces.

The character of the shock wave in many respects depends on the shape of the surface in the flow. If the surface is perpendicular to the flow of air, the shock is located across the flow; in this case the shock is called a normal shock. If the body has a pointed surface, the shock will be inclined toward the flow; in this case the shock is called an oblique shock. The more pointed the body, the greater the inclination of the shock toward the flow. The wave resistance in an oblique shock is less than that in a normal one. A shock wave cannot appear on an entire surface, but only on a certain part of it. In this case the shock wave is called a local shock wave. Local shock waves are possible even for bodies that are flying with subsonic velocity. For preventing normal shock waves, the wings of antitank missiles (SS-11) are given a unique sweptback shape (Fig. 12). Sweptback wings can be turned with the peak forward (a) or backward (b). This type of wing configuration and the tapering of their leading edges seems to ease the effect of air compressibility by converting a normal shock wave into an oblique one, which considerably decreases the air resistance.

We shall explain how lift occurs. Let us place the wing of an aircraft in an air flow in such a manner so that the velocity vector of the air flow is not directed along the axis of cross-section of the wing (Fig. 13), but at a certain angle α to it.

In this case the pattern of flow will change. Streams of the air flow will start to divide at a closer distance from the leading edge of the wing. The flow around the wing will become asymmetric. The velocity of the air will be greater above the wing, and less under the wing. From the laws of gas dynamics it is known that if the velocity of a gas is greater, the pressure is less, and conversely. Consequently, the pressure above the wing will be less than the pressure under the wing. Due to this difference of pressures, there appears a force R that acts at a certain angle toward the direction of flow; it is called the total aerodynamic force. The magnitude of this force depends on the magnitude of angle α, which is formed by the wing and the air flow. In aerodynamics this angle is called the angle of attack (the angle at which the air flow attacks the wing).

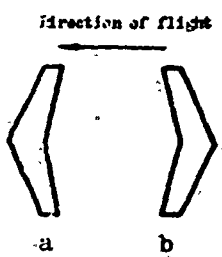

Fig. 12. Swept-back wings.

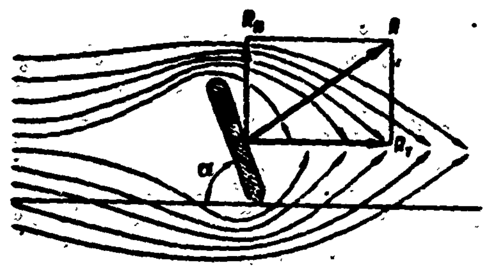

Fig. 13. Expansion of total aerodynamic force R into two components: drag R_T and lift R_N (α is the angle of attack).

The total areodynamic force (Fig. 13) spreads out into two forces. One of them is directed along the air flow, while the second is perpendicular to it. The force that is directed along the air flow is called drag R_T. The force that is perpendicular to drag is called lift R_N.

It should be noted that lift will not always raise a flight vehicle. If a wing is given a negative angle of attack (Fig. 14), lift will be lower. The greater the angle of attack, the greater the lift. However, this is valid up to a certain magnitude of the angle of attack. With a further increase of the angle of attack, lift does not increase, but decreases. It is also obvious that if the angle of attack is equal to zero, lift also is equal to zero. It should be borne in mind the expansion of the total aerodynamic force into components is conditional; this is done for the convenience of aerodynamic calculations. In reality, there exists only one total aerodynamic force, the action of which is equivalent to the action of the two above-indicated forces.

In the presence of the angle of attack, lift is created not only by the wings, but also by the body and the horizontal rudders. Total lift prevents flight vehicles that are heavier than air, including antitank guided missiles, from falling to the ground.

Attention should be given to one more circumstance. We explained that lift appears in a plane wing only in the presence of an angle of attack. However, if we make a wing with an asymmetric profile, lift of such a wing will apear even at a zero angle of attack (i.e., when $\alpha = 0$).

In the presence of smooth convexity on the upper side of the airfoil (Fig. 15) and slightly noticeable convexity (or concavity) on the lower side of the airfoil together with smooth curvature of the tip of the airfoil, the velocity of the air streams above the airfoil is increased. Due to the increase of the velocity the air streams above the airfoil, rarefaction will form, and consequently, lift that is directed upwards occurs. It is very important that the air streams flow smoothly around the airfoil, do not detach from its surface, and do not turn into air vortices.

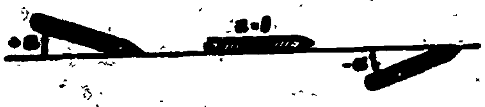

Fig. 14. Various angles of attack (α) of a wing.

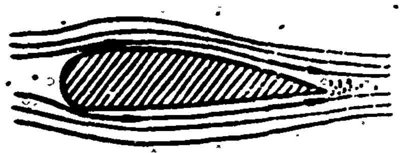

Fig. 15. Flow around an asymmetric airfoil.

Having explained the nature of lift, we shall consider the design of the separate components of the airframe.

The body of an antitank missile is a hollow solid of revolution that is made from a light, but strong material, for instance aluminum alloys. The body of a missile that is flying at a low velocity (100-200 m/sec), usually has a cylindrical shape with a conical nose.

The generatrix of the cone can not only be a straight line, but also a curve (for instance, a circular arc). The shape of a nose cone with a curvilinear generatrix is said to be ogival. For decreasing the resistance to air, the nose cone of the body of the 9-BÉBÉ supersonic antitank missile is tapered.

The missile body has compartments for the warhead, stabilizers, guidance equipment, and rocket engines.

As already noted the missile body also participates in the creation of lift. However, the area of the body is too small for creating the necessary magnitude of lift. Therefore, the antitank missiles that we have considered, except the 9-BÉBÉ, have wings which, together with the body, create the required magnitude of lift.

The wings (plane) are thin plates or have a thick streamlined profile. Plane wings have various shapes. The wings of missiles that possess subsonic velocity are rectangular (Mosquito), sweptback (SS-11), and in the shape of a right-angle trapezoid whose acute angle faces the direction of motion (Pye, Malkara, Mebus).

It shou 1 be noted that antitank missiles have four wings: two of the wings are located in the horizontal plane and two in the vertical plane. Why was it necessary for missiles to have four wings? This is explained by the fact that a pair of wings located in the vertical plane is necessary for controlling a missile in the horizontal plane. Therefore, in order to control a missile in the horizontal plane just as in the vertical plane, it is necessary to install one more pair of wings. Both pairs of wings do not have to be located in the vertical and horizontal planes (cruciform). They can also be arranged in the form of an X. This arrangement makes it possible to somewhat increase the dimensions of a missile, since with

identical wingspans (in the case of the X-arrangement) the distances in the horizontal and vertical planes between the wingtips will be less than the span of the wing itself.

There is one more wing design, i.e., annular; an example of this design is illustrated by the Lutin missile. These wings consist of a cylinder that is attached to the body with the help of struts.

If a missile that is equipped with an engine and wings is launched, it will fly. However, it cannot be controlled. A missile could be controlled if it was outfitted with rudders. There are different types of rudders, e.g., aerodynamic and gas.

Aerodynamic rudders are made in the form of plates of various shape with a streamlined profile (for instance, the Dart missile) or in the form of spoilers (the SS-10 missile and others).

Aerodynamic rudders that are made in the form of plates are located on the body, just as the wings, in two planes. In distinction from wings, these rudders are smaller in size and have an axis around which they can revolve, thus forming angles with respect to the longitudinal axis of the missile body, and consequently, with respect to the air flow. These angles are called the rudder deflection angles. We already know that if a plane wing is placed at a certain angle to the air flow, the resisting force of air may be represented in the form of two components: drag and lift. If the wing forms an angle of attack with the horizontal plane, lift occurs; if the wing forms an angle with the vertical plane, a lateral force occurs. These aerodynamic forces, which are created by the deflected rudders, are also used for controlling the missile, i.e., for turning to the right and left, and up and down.

Aerodynamic rudders are placed behind or in front of the wings. When selecting the place of location of the wings and rudders, it is necessary to consider the missile's stability in flight. The wings and rudders must be placed on the body in such a manner so that the missile does not overturn during flight.

Missile stability requires that the element (wing or rudder) located in front has an angle of attack that is greater than the angle of attack of the element located in back. During the flight of a missile, its longitudinal axis assumes such a position at which the moments[1], formed by the lift of the rudder and wing

[1]The moment of the force with respect to a given point is the product of the force multiplied by the length of a perpendicular dropped from the given point to the line of action of this force. The length of the perpendicular is called the arm of the moment.

would be equal with respect to the center of gravity. This equality of moments may be expressed in the following form:

$$R_{N_p} l_p = R_{N\text{кр}} l_{\text{кр}}, \qquad (1)$$

where R_{Np} and $R_{N\text{кр}}$ is the lift of the rudder and wing, respectively; l_p and $l_{\text{кр}}$ are the arms of the moments formed by the lift of the rudder and wing, respectively.

Lift R_N is proportional to the angle of attack α; therefore, it can be presented in the form of two co-factors:

$$R_N = R'_N \alpha,$$

and expression (1) can be rewritten in the following manner:

$$l_p R'_{Np} \alpha_p = l_{\text{кр}} R'_{N\text{кр}} \alpha_{\text{кр}}. \qquad (2)$$

We shall designate

$$l_p R'_{Np} = C_p,$$

$$l_{\text{кр}} R'_{N\text{кр}} = C_{\text{кр}}.$$

Introducing these designations into expression (2), we obtain

$$C_p \alpha_p = C_{\text{кр}} \alpha_{\text{кр}}.$$

Let us assume that the rudders are located in front of the wings (Fig. 16a) In this case $\alpha_p > \alpha_{\text{кр}}$. In order to satisfy equality (1), it is necessary to have $C_{\text{кр}} > C_p$. If, however, the equality satisfies this condition, then upon deviation of the longitudinal axis of the missile from the equilibrium position (as a result of a gust of wind or for some other reason) the missile will return itself to the equilibrium position. Let us assume that the missile revolves counterclockwise (nose upwards) at angle $\Delta\alpha$; in this case the moment of the rudder will change by the quantity $C_p\Delta\alpha$, and the moment of the wing, by the quantity $C_{\text{кр}}\Delta\alpha$. Since $C_{\text{кр}} > C_p$, the moment of the wing with respect to the center of mass will be greater than the moment of the rudder, i.e.,

$$C_{\text{кр}} (\alpha_{\text{кр}} + \Delta\alpha) > C_p (\alpha_p + \Delta\alpha).$$

Due to this inequality of moments, the missile returns itself to the initial position of equilibrium.

If the missile's rudders are located behind the wings, the angle of attack of the rudders should be negative (Fig. 16b) in order to observe the condition of $\alpha_{\text{кр}} > \alpha_p$ and $C_{\text{кр}} < C_p$. Upon fulfillment of this condition, after deviating from the position of equilibrium, the missile will return to it.

It is clear from the statements made above that the rudders play a dual role: first, they do not allow the missile to overturn, i.e., they make the flight of

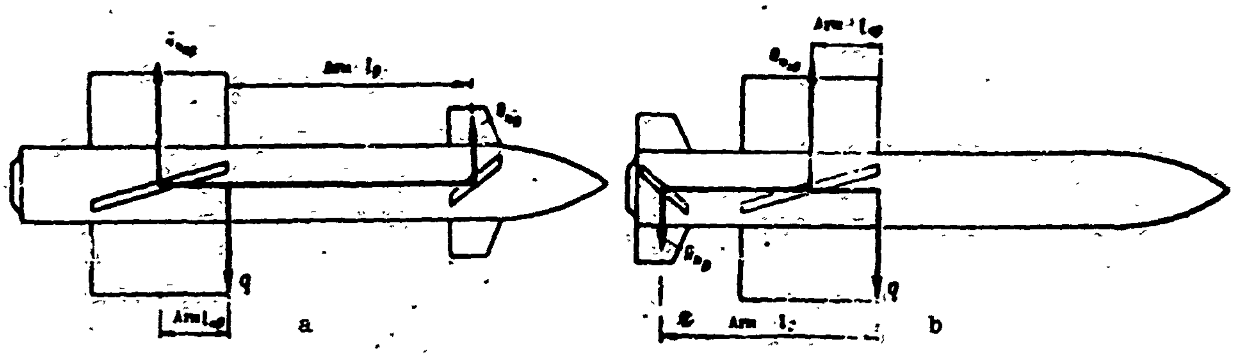

Fig. 16. Aerodynamic designs: a) canard; b) normal

the missile stable; secondly, the missile is controlled with the help of the rudders. If the rudders only purpose is to make the missile stable (in this case they do not turn), they are called stabilizers.

The small size of the rudders as compared to the wings is of significance, although they compensate the moment created by the lift of the wings. This is explained by the fact that the moment of lift must be compensated, and not the force itself. The moment of lift in this case is the product of the lift multiplied by the distance between the center of pressure and the center of gravity (this distance in the given case is the arm of the moment of lift). Consequently, the value of the moment of lift not only depends on the value of the lift, but also on the value of the arm. The creation of a compensating moment does not require a large force. It is possible to have a smaller force, but the arm will then have to be large. As can be seen from Fig. 16a and b, the lift of the rudders is actually less, and the arm is greater; therefore, the moments are equal.

If the wings of a missile are arranged in the back, and the rudders are in front, it is said that the missile has a "canard" aerodynamic design. This configuration is the one used in the Lutin and Mebus missiles. If the wings are located in front, as in an aircraft, and the rudders are in the back, this aerodynamic design is said to be normal (the Dart and others). Each aerodynamic configuration has its advantages and disadvantages. The canard configuration has the following positive properties: the lift of the wings and the lift of the rudders are in the same direction, i.e., upwards. Consequently, the rudders also participate in compensating the gravity of the missile. Because of the rudders in this case, the wings can be made somewhat smaller, which means that the dimensions of the missile also will be smaller.

In the normal configuration, the wings must be somewhat enlarged, in order to

compensate not only the gravity of the missile, but also the force created by rudders which, in the normal configuration, is directed downwards. In the normal configuration, the rudder is located behind the wings; the wings distort the flow of air and somewhat impede the work of the rudders. This deficiency of the normal configuration is eliminated by moving the rudders close to the wings. In this case the wings and the rudder seem to be one unit. This version of the normal configuration has been called the "flying wing", or "tailless" configuration; it is employed in a large number of missiles (SS-10, SS-11, Entac, Cobra-I, Pye, and others).

We now shall consider the action of aerodynamic rudders as control devices. The stability of an antitank guided missile is created due to the appearance of a restoring moment. Let us assume that a missile with a canard configuration flies too high and does not hit the tank. It must be made to fly lower. This requires the application of some force directed downwards to the missile. This force can be created horizontal rudders, if their angle of attack (in the given specific case) is decreased, i.e., if they are turned at a certain angle with respect to the axis of rotation. Then their lift will decrease and the moment with respect to the center of gravity will be less than the moment of lift of the wings. Due to the inequality of moments, the missile will turn around the center of gravity at a certain angle, and will occupy an oblique position (nose downwards). The missile, while continuing its flight, will descend lower. When the missile attains the necessary altitude, the horizontal rudders should be turned in the opposite direction, so that the moments are equal again. The missile will fly horizontally.

The same procedure is following if the missile must be turned to the right or to the left. However, in this case it is necessary to turn not the horizontal rudders, but the vertical ones. The reader can figure out for himself which rudders must be turned and in what direction for a normal missile configuration.

Spoilers. We have considered the action of aerodynamic rudders. The SS-10 missile and certain others employ so-called spoilers (Fig. 17) as rudders. They consist of thin continuously oscillating plates. They are placed in the middle (Fig. 17a), of the wings or on their tips (Fig. 17b). They also can be placed on the fins. Spoilers that are mounted on the horizontal wings, in accomplishing continuous oscillations up and down, move behind the wings upwards or downwards. If the time that the spoilers remain above and below is equal, they practically do not render any action on the direction of flight of the missile. If, however, they are in one of the positions longer than in the other, they create an additional

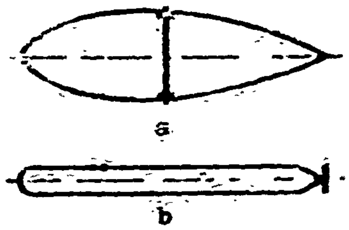

Fig. 17. Spoilers with central and tip location.

force and act like horizontal rudders.

Spoilers that are mounted on vertical wings move behind the wings to the right or to the left and act like aerodynamic rudders. If the missile turns during flight (for instance, the SS-10 missile), each spoiler acts alternately: first as an elevator, and then as a rudder. Spoilers that are mounted on fins act the same way. Spoilers are actuated by comparatively low-power devices, for instance electromagnets, etc. However, spoilers somewhat increase missile drag, since the planes of their plates are arranged perpendicular to the air flow.

Gas rudders. Gas rudders consist of plates made from a heat-resisting material, graphite for instance. They are placed in the stream of gases flowing from the nozzle of a jet engine (Fig. 18). The action of gas rudders differs in principle from the action of aerodynamic rudders.

We see from Fig. 18 that a force R appears as a result of the deflection of a gas rudder. This force may be broken down into two components, from which one force, Q, is directed along the axis of the missile, and the other N, is perpendicular to it.

Force N, when combined with thrust, changes the magnitude and direction of the latter. The direction or altitude of flight is changed as a result of this.

The direction of flight of a missile may be changed by intensifying or reducing the action of the reactive force by means of turning the entire engine. This is attained in the Pye missile by overlapping one or several of the nozzles that are located around the circumference of the tail section of the missile body.

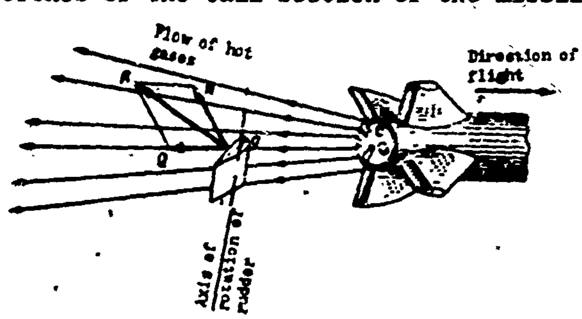

Fig. 18. Action of gas rudders.

5. ATGM STABILIZATION DURING FLIGHT

Some antitank missiles revolve during flight (SS-10), others do not (Entac). Why do certain missiles revolve, and others do not?

During the flight of a missile, it can roll or turn under the action of the wing, for example. If a missile that possess roll is launched (not to mention turning), the planes of its wings and rudders will not be horizontal and vertical. In this case, the commands transmitted to the rudder will not lead to a desirable result, since the additional forces that appear when the rudders are turned will not act in the vertical or horizontal plane, but in slanted planes. For instance, it is necessary to turn the missile to the right; it then turns not only to the right, but it also will be inclined with its nose downwards. If, however, it is turned, then, in general, it is not known how it will execute the given command. This circumstance is taken into account and the missile is designed in such a manner so that it does not roll, i.e., it is stabilized with respect to roll. Nonrotating missiles have a special device for this which makes sure that the missile does not roll, and if roll does occur, it immediately eliminates it. This device consists of two critical components: a gyroscope and ailerons.

The gyroscope is a sensing device with whose help it is possible to detect roll of a missile.

A Gyroscope (Fig. 19) is constructed on the same principle as a "top". In gyroscopic instruments it is made in the form of a fast-revolving symmetric rotor 1, that is mounted in a gimbal suspension which consists of two frames: the outer 2 and the inner 3. In the gimbal suspension the axis of normal rotation of the rotor is perpendicular to the axis of rotation of the inner frame, which in turn is perpendicular to the axis of rotation of the outer frame. All these three

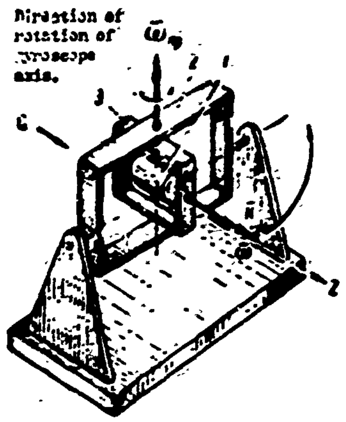

Fig. 19. Diagram of a gyroscope: 1 — rotor; 2 — outer frame; 3 — inner frame.

mutually-perpendicular axes intersect at one point which remains fixed with respect to the base of the gyroscope even when the frames are revolving.

If a gyroscope can revolve around two gimbal axes, it is called a gyroscope with three degrees of freedom. The third degree of freedom of the gyroscope is rotation with respect to its own axis Z.

If a gyroscope can revolve only with respect to one axis, such a gyroscope is called a gyroscope with two degrees of freedom. If the gyroscope whose diagram is shown in Fig. 19 is rigidly mounted on the outer frame, we will obtain a gyroscope with two degrees of freedom.

The rotor of any gyroscope revolves very rapidly, making 30 thousand revolutions per minute and more. This is constructively possible, for instance, if the gyroscope is made in the form of the rotor of an electric motor. Due to the very fast rotation of the rotor with respect to its own axis, the gyroscope also obtains a property that is widely used in contemporary technology, i.e., it maintains a constant attitude and resists any attempts to change it. Let us consider this property of the gyroscope in greater detail.

Let us assume that the gyroscope shown in Fig. 19 can revolve rapidly around its own axis. If we strike the inner frame of the rotor (in other words, apply an impulse moment of external forces), it will revolve together with the inner frame, like an ordinary solid, by inertia in the direction of action of the applied moment. When the outer frame is struck, the rotor will revolve around the axis of this frame.

Now we shall rotate the gyroscope rapidly with respect to its own axis Z. Again we shall strike the inner frame of the gyroscope. In this case the axis of the rotor will not change its position. If, however, the gyroscope does not spin enough, its axis will accomplish small oscillations with respect to its initial position. In the gyroscopes that are applied in practice these oscillations take place, but their amplitude is so low, and their frequency is so high that they are invisible to the naked eye.

We shall apply a constant force Q to the outer frame of the gyroscope. The gyroscope will start to turn with respect to the axis of the inner frame. It will turn as long as force Q acts. This force will stop, i.e., the gyroscope will cease

to rotate. If we apply force Q to the inner frame, the gyroscope will start to turn with respect to the axis of the outer frame. Thus, the axis of the gyrorotor, when it is spinning, does not move in the direction of action of the force applied to it, but in a direction that is perpendicular to the action of the applied force. When the axis of the gyroscope accomplishes such motion, they say that it precesses. And the motion itself is called precession.

There is a rule for determining the direction of precession. According to this rule, the end of the axis along which the angular velocity of rotation of the gyrorotor is directed tends to combine with the vector of the moment of the external forces under the action of the moment of the external forces. The rule of precession can also be stated in another way: under the action of the moment of the external forces, the angular-momentum vector tends to combine with the direction of the vector of the moment of the external forces by the shortest route.

The angular momentum of a gyroscope is the product of the moment of inertia of the rotor J_Z with respect to the axis of its normal rotation multiplied by the angular velocity of normal rotation of the rotor Ω. The moment of inertia of the rotor J_Z is equal to the sum of the products of the mass of all particles of the rotor multiplied by the square of their distance from the axis of rotation:

$$J_z = \sum mr^2.$$

The magnitude of the moment of inertia characterizes the distribution of the rotor's mass with respect to the axis of rotation Z. The moment of inertia is greater, the greater the distance the particles of the rotor are from the axis of rotation.

The rule of precession in the last formulation is expressed mathematically in the following manner:

$$\bar{H} = J_z \bar{\Omega}.$$

In Fig. 19 it is clear that the angular-momentum vector $\bar{H}$ is directed to the same side as the vector of angular velocity $\bar{\Omega}$. If we look at the end of vector $\bar{H}$, the rotation of the rotor should occur counterclockwise.

The magnitude of the angular momentum determines the magnitude of the angular rate of precession. The greater the angular momentum of a gyroscope, the greater the magnitude of the moment of external forces which must be applied to it in order to obtain the necessary angular velocity of precession. Consequently, a gyroscope with a large angular momentum will have a smaller reaction to external disturbances,

i.e., it will be more stable to the influence of external forces.

The angular velocity of precession is determined by the formula

$$\omega_{\text{пр}} = \frac{M}{H \sin \theta} = \frac{M}{H \cos \beta},$$

where θ is the angle between the axis of the rotor and a perpendicular to the plane of the outer frame; β is a 90° angle minus θ; M is the moment of external forces applied to the gyroscope.

If $M = 0$, i.e., if a moment of external forces is not applied to the gyroscope, then $\omega_{\text{пр}} = 0$, i.e., the gyroscope does not precess. Precession appears instantly when $M > 0$ and also instantly disappears when the moment of the external forces becomes equal to zero.

If a gyroscope is acted upon by an impulse moment of external forces, the deviation of the gyroscope's axis will be insignificantly small. This property is also used for determining the roll angles of an antitank guided missiles [ATGM] (ПТУРС). Contemporary missiles use the gases of solid-propellant engines to make the gyroscope rotate rapidly.

The gyroscope (Fig. 20) is placed inside the missile in such a manner so that the axis 2 of the flywheel 1 is in strictly defined position with respect to the longitudinal axis of the missile (in Fig. 20 the longitudinal axis of the missile coincides with the axis OX).

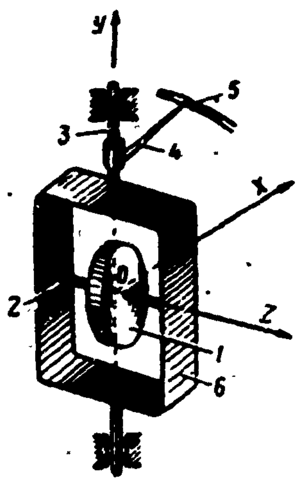

Fig. 20. Gyroscope: 1 — flywheel; 2 — axis of flywheel; 3 — axis of frame; 4 — contact; 5 — half-riding; 6 — frame.

If there is no roll, then contact 4, which is connected to axis 3 of the gyroscope, frame 6, is in the neutral position, at which the source of electric current is disconnected from the devices that actuate the special units for eliminating roll, i.e., the ailerons. When the missile rolls, its body will turn, together with the half-ring 5 mounted on it, at a certain angle with respect to the longitudinal axis of the missile. Axis 2 of flywheel 1 and, together with it, the axis of the gyroscope, will then maintain their attitude. Due to this, contact 4 also will maintain its initial position. Half-ring 5, turning together with the body of the missile, will slide along contact 4, disconnecting the source of current to the devices which actuate the ailerons. The ailerons, after being actuated, act on the missile, which starts to turn around the longitudinal

axis in the direction opposite the direction of roll. When roll disappears, contact 4 again appears in the neutral position and disconnects the source of electric current. The ailerons will occupy their former position. The missile will cease to turn.

Let us discuss the action of the ailerons. Hinged plates are mounted on the wings. In the neutral position the plates comprise one surface with the wings (Fig. 21). When there is no rolling, these plates, which are called ailerons, compose on plane with the horizontal wings. If, however, there is rolling, the ailerons must be turned around their axis and given a deflection angle (the magnitude of the deflection angle depends on the magnitude of roll). One aileron is then deflected, e.g., upwards, and the other, downwards (or, conversely, depending upon the direction in which the missile rolled — to the right or to the left). The deflecting from the plane of the wings, the ailerons change the magnitude of their lift. When the ailerons are not deflected, their angle of attack is equal to the angle of attack of the wings. But when they are deflected, their angles of attack are changed in opposite directions (for instance, the right aileron is deflected downwards, and the left upwards). Lift appears due to the change of the angles of attack: for instance, the lift of the right aileron is directed upwards, and the lift of the left aileron directed downwards. These lifts, which directed to different sides, will turn the missile in such a manner so that roll does not occur (Fig. 22). Then the ailerons again will occupy their former position, i.e., they will not be deflected, but will lie in one plane with the wings. The moment that roll disappears is determined by the gyroscope.

There are antitank missiles which revolve during flight. These missiles include, for instance, the SS-10. A missile is revolved so that the accuracy of its flight on a trajectory is not affected by the eccentricity of the thrust, and also the deviations permitted in the manufacture and adjustment of the missile body, wings, and tail unit. During the rotation of a missile, the direction of action of the permitted deviation will continuously change, as a result of which the missile will fly on the given trajectory without deviating to the side. These missiles have one more device, the collector, which is intended for separating a given command between the horizontal and vertical rudders at their given position with respect to the longitudinal axis of the missile. During rotation of the missile, the position of the rudders constantly changes; therefore, to turn the missile to the right and to the

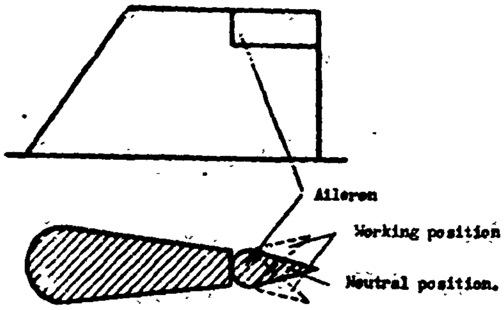

Fig. 21. Aileron.

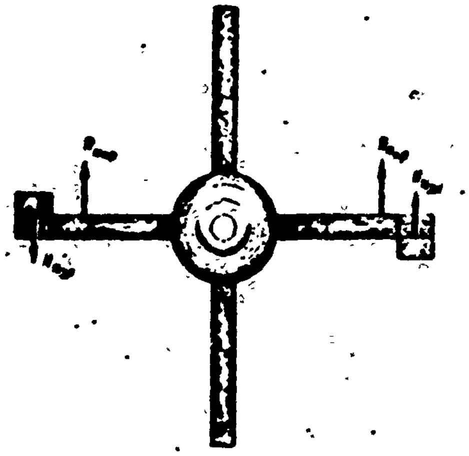

Fig. 22. Action of an aileron: $R_{N\text{жр}}$ — wing lift; $R_{N\text{эл}}$ — aileron lift.

left, or upwards and downwards, it is necessary to deflect the aerodynamic rudders when they are in the horizontal and vertical positions. The collector should send a command to the rudders when their deflection will turn the missile only in one plane (or in two, if necessary) at the required magnitude.

Figure 23 shows a diagram of a simple collector which consists of a ring whose axis 2 is stabilized by the gyroscope, and brushes 1 which are connected to the body of the missile. The collector ring is divided into four sectors which maintain their position (do not revolve) during flight of the missile. The sectors are connected to the aerodynamic rudder actuators. The brushes are joined to the body of the missile and revolve together with it, sliding along the sectors of the ring. Since the sectors maintain a strictly defined position, the actuators operate only when the aerodynamic rudders are in a definite position. The peak value is attained by the controlling force of the aerodynamic rudders at every 90° turn of the missile with respect to the longitudinal axis. The aerodynamic rudders exchange functions when they make a 90° turn: the horizontal rudders operate like the vertical ones, and conversely. Pairs of aerodynamic rudders alternately control the missile in the horizontal and vertical planes. In certain missiles, e.g., in the SS-10, the pairs of spoilers are not actuated at 90°, but every 180°.

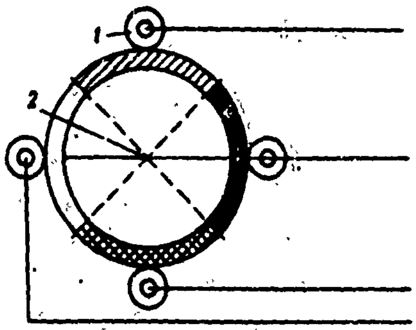

Fig. 23. Diagram of a simple collector: 1 — brushes connected to body of missile; 2 — axis stabilized by gyroscope.

6. ATGM GUIDANCE SYSTEM

A tank is a very small and extremely mobile target. Therefore, a large role is played by accuracy when firing on tanks.

For increasing their firing accuracy, antitank rocket missiles are guided. Control of the motion of a missile after it has left the launcher makes it possible to eliminate the numerous errors that accompany any firing, or at least decrease them to a considerable extent. For instance, it is practically impossible to aim exactly at a tank. A gunner must allow for errors both in range, as well as in direction when sighting. Errors will arise due to the inaccuracy of determining and calculating the meteorological factors, the action of gusts of wind, whose influence generally cannot be taken into account, and also when the target will maneuver. The errors due to target maneuver can be very large, and it is impossible to consider them beforehand. Each of the enumerated errors by themselves can be slight, but altogether they can noticeably influence the accuracy of firing.

Control of a missile during its flight makes it possible to eliminate or decrease all of these errors. In order to control a rocket missile in flight, it is equipped with a system of instruments which, combined with the instruments at the command post, are called the guidance system. As we know from the first section of the book, [ATGM] (ПТУРС) employ two guidance systems: remote-control and self-contained. All foreign missiles except the 9-BÉBÉ have a remote-control system.

Remote-control system. There are presently quite a few types of remote-control systems. They differ from one another both in design, as well as in the means utilized for transmission of the command signal (i.e., the signal that the operator sends by means of a transmitter to the receiving equipment of the missile for changing the direction of its flight). The generation of the command signals, which have one

quality or other depending upon the mutual location of the missile and the target, and their transmission from the command post by means of transmitting equipment are common for all these systems. The command signals, which are received by the equipment located on the missile, are amplified and finally act upon the rudder actuators. The rudders are deflected and the missile changes its direction of flight to the required direction.

The command signals are transmitted from the command post by radio or by wires. Most foreign missiles have a remote-control system with wire-transmission of commands. Let us first analyze the principle of action of a remote-control system with radio-transmission of commands.

Any guidance system consists of a number of component parts, i.e., blocks. The layout of a guidance system is usually represented in the form of a combination of these blocks and is called a block diagram. A block diagram of a remote-control system with radio-transmission of commands is shown in Fig. 24. This type of guidance system includes the following components: a command-encoder block, a radio communications link, a decoder-actuator block, and sometimes a monitoring system. Let us examine the functions of the enumerated blocks.

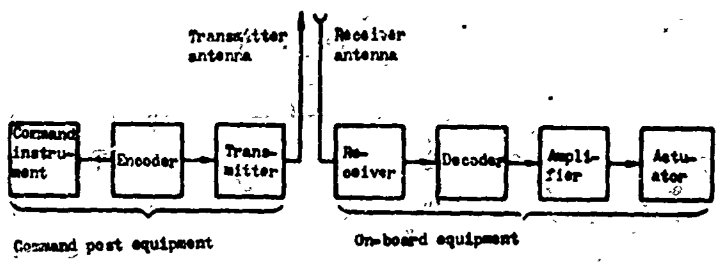

Fig. 24. Block diagram of remote-control system with radio transmission of commands.

To make the missile accomplish the required maneuver, i.e., turn to the right or to the left, descend or ascend, the missile must be given a command. The operator who observes the missile's flight and determines the mutual position of the missile and tank determines which command must be send. For instance, if it is necessary to turn missile to the right, the command "To the right" is given. How is it sent? The command-encoder block is used for this purpose. It consists of two units: the command unit and encoder unit. The command unit of the block, which is called the command instrument, creates (generates) the command. This instrument is actually a command transmitter. The operator turns the handle of the command instrument to the right, which then generates electrical pulses. An electrical pulse is a very

brief single jump of current or voltage in an electrical circuit. Electrical pulses are characterized by the size of the jump, the duration, and the polarity ("plus" or "minus"). Electrical pulses are subdivided into high-voltage pulses, high-intensity pulses, and radio pulses.

A radio pulse is the brief influence of voltage or current on radio equipment. Radio equipment uses pulses from a fraction of a microsecond (a microsecond is one thousandth of a second) to several milliseconds (a millisecond is one millionth of a second) in duration. The process of pulse control is called pulse modulation.

Figure 25 graphically shows a pulse of 1 direct current and a radio pulse 2. The operator can send four types of commands: "right," "left," "down," and "up." So that the receiving equipment on the missile can distinguish which command the received electrical pulses refer to, they must have a fully defined duration and a strictly defined combination for each command. The function of conversion of the electrical signals of the command instrument into the number and combination of electrical pulses for the given commands is executed the second components of the command-encoder block, the encoder. The necessity of the encoder is brought about by the following circumstances. They include atmospheric and industrial interferences which may cause a "failure", i.e., nonfulfillment of a command by the actuators. Interferences in the form of electrical signals can appear during lightning discharges, from operating electric motors and other electric equipment. Finally, radio interference can be intentionally created by the enemy, who tries to disturb the normal control of the missile and sends special signals to the missile, which is known as "false actuation" and consists in the execution of false commands that are sent to it.

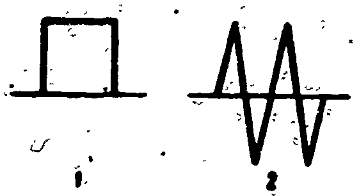

Fig. 25. Graphic image of a pulse: 1 — direct-current pulse; 2 — radio pulse.

The transmitter serves for transmission of formed and encoded commands; it transmits encoded commands through a radio communications link to the receiving equipment of the missile. The commands that are transmitted by the transmitter are received by the receiving device.

The commands are decoded by the decoder, which is a device that reacts only to a given combination of pulses of a fully defined quality. Of all the possible electrical pulses received by the receiving device, the decoder transmits only the group or sequence of groups to which it is tuned. The receiver can pick up the

static and interference of the enemy, but the decoder will not react to them and will not transmit them to the actuators.

The encoder and decoder form the so-called selector device, which codes the control commands in the transmitting portion and identifies them (in other words, it selects them) in the receiving portion. There are many criteria by which it is possible to distinguish the various commands. In connection with this, there exist several types of selection: qualitative, code, combinational, etc. Qualitative selection is based on the distinction of signals with regard to the polarity of pulses, their frequency, and duration. Code selection is based on the distinction of pulse combinations in a strictly defined sequence. Code selection makes it possible to carry out a remote-control system that is noise proof not only with respect to naturalinterferences, but also specially created ones.

In combinational selection the actuators are triggered only by the simultaneous or strictly sequential actuation of several output elements of the decoder. This the most reliable form of section and, at the same time, the most complicated in the technical aspect.

The command signals enter the amplifier from the decoder.

The command instrument, encoder, and transmitter are located at the command post. The receiver, decoder, amplifier, and actuators are located on the missile and make up the so-called on-board equipment.

As an example, we shall analyze the principle of operation of the command-encoder block of a remote-control system with radio transmission of commands and qualitative selection. Let us assume that the command "Right" corresponds to the frequency of electrical pulses f_1, "Left" to frequency f_2, "Up" to frequency f_3, and "Down" to frequency f_4.

For controlling the missile's motion it is important to determine not only the sign of the transmitted command, but also its magnitude. In particular, this can be done by establishing a specific relationship between the duration of the commands with respect to time. Let us assume that in the missile control channel in the horizontal plane the transmission time of the commands "Right" t_1 and "Left" t_2 is constant and equal to T. The distribution of this time between commands can be extremely diverse: from $t_1 = T$ and $t_2 = 0$, to $t_1 = 0$ and $t_2 = T$. The time relationship between commands of the horizontal control channel is characterized by the so-called command factor, which is equal to

$$K_{г.к} = \frac{t_1 - t_2}{T}.$$

It is easy to note that the value of the command factor varies from +1 to -1. An absolutely analogous expression may also be written for the vertical control channel. If the sending time of the commands "Up" is τ_1, and "Down" is τ_2, the command factor for the vertical channel will be equal to

$$K_{в.к} = \frac{\tau_1 - \tau_2}{T}.$$

The magnitudes of the command factors are varied with the help of the command instrument. A fundamental diagram of a simple command instrument is shown in Fig. 26. The instrument consists of the following basic elements: special shafts 1 and 5, electric motor 2, control stick 3, and contact groups 4 and 6. Shafts 1 and 5 are turned by electric motor 2. Control stick 3 is mechanically coupled to contact groups 4 and 6. By changing the position of control stick, the contact groups are forced to slide along the generatrices of the shafts. Each contact group (Fig. 27) consists of three contact plates, whereby contacts a and b are closed in the normal position. Contact a is connected to a generator of frequency f_1, and contact c is connected to a generator of frequency f_2. The shaft has a ridge which divides its surface into two parts of equal area. The shaft revolves with a constant speed, and the time of its complete revolution is equal to T. Contacts b and c close when the contact group slides along the shaft. If the contact group is in the middle of the shaft, the time that contacts a, b and b, c remained in the closed state is identical and equal to $\frac{T}{2}$. Consequently, in one of the half-periods the middle contact (and the transmitter across it) is connected to the generator of frequency f_1, and in the next half-period it is connected to the generator of frequency f_2. Then

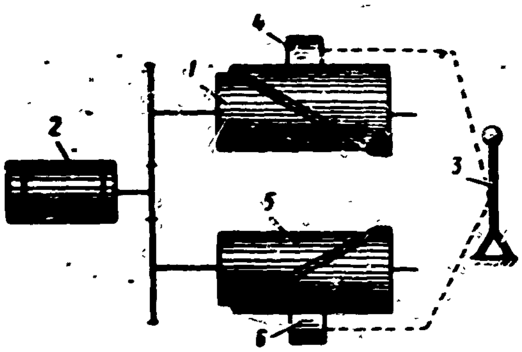

Fig. 26. Diagram of command instrument: 1 and 5 — shafts; 2 — electric motor; 3 — control stick; 4 and 6 — contact groups.

$$t_1 = t_2 = \frac{T}{2}, \quad K_{г.к} = 0.$$

If, however, the contact group is displaced from the middle position to the left, the closing time of contacts a and b will be greater than the closing time of contacts b and c and $K_{г.к.} > 0$.

Thus, with the help of the command instrument, the operator changes the command

factor and thereby control the motion of the missile in the horizontal plane. The missile is controlled in the vertical plane by precisely the same method. For this, the command instrument has one more shaft 5 and contact group 6 (Fig. 26), the middle contact of which, and consequently also the transmitter, are connected first to the generator of frequency f_3, and then to the generator of frequency f_4.

The transmitter can simultaneously transmit signals for frequencies (f_1, f_3), (f_1, f_4), (f_2, f_3), (f_2, f_4) which belong to different channels and correspond to the commands "Right — down," "Right — up," "Left — down," and "Left — up," correspondingly. Transmission of the control signals usually employs the ultrashortwave range of radio waves.

The remote-control system with radio transmission of commands is susceptible to interferences. Therefore, in this type of guidance system they try to take all possible measures, on the one hand, to hamper enemy detection of the transmission of commands to the missile, and on the other hand, to decrease the interferences created by the enemy. The interferences created by the enemy are decreased by devices that discriminate the useful signal from an interference signal. Furthermore, directional antennas are employed on the missile and for transmitter, as done, for instance, on the Latin missile. Directional antennas can receive and transmit signals only within the limits of a narrow sector.

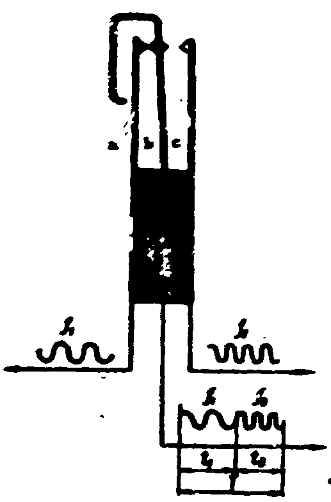

Fig. 27. Diagram of contact group.

A remote-control system with wire transmission of commands also contains command-encoder and decoder-actuator blocks. Instead of the radio communications link here, a wire communications line is used. This significantly simplifies the equipment, since it is not necessary to have a radio transmitter at the command post and a radio receiver included in the on-board equipment.

To transmit the required number of commands through the smallest possible number of wires, the polar and amplitude qualities of current pulses are used, i.e., the fact is taken into account that an electrical pulse is characterized not only by a definite magnitude, but also a definite sign. Thus, for instance, a

positive current pulse of a definite magnitude is ascribed by the value of the command "Up," and a negative one by the command "Down." Usually a remote-control system with a wire communications line for antitank guided missiles has two wires. These systems permit the transmission of the "Up" and "Down" commands to the elevators, and the "Right" and "Left" commands to the rudders.

The wire communications line has high interference protection from various kinds of interferences, and it is also simple to operate.

The missiles are usually controlled by steel wires 0.2 to 0.3 mm thick. They are wound on special coils that are located on the missile; during missile flight the wires are unwound from the coils.

Missiles that have a remote-control system with wire communications and radio communications are controlled identically. The operator, with the help of an optical sight that is connected to the control stick, tracks the missile's flight by means of the luminescent trail created by the exhaust gases of the jet engine or by means of a tracer, and, by turning a lever on the control panel, he transmits the commands "Up," "Down," "Right" or "Left" to the missile in the form of electrical signals. The decoder-actuator block, which is mounted on the missile, decodes these signals, transforming them into electrical pulses which are sent to devices that vary the position of the controls.

Incidentally, one should note that the trajectories of remote-controlled antitank rocket missiles shot from launchers and from the ground, are not straight lines.

So that a missile does not cut into the ground immediately after launching, it is launched at a certain angle. After the missile flies a certain distance, the operator lowers it downwards to the required altitude. The missile flies horizontally at this altitude until target impact. The phase of the trajectory from the launcher to the beginning of the horizontal phase is called the entry phase. The operator guides the missile in this phase in the required direction and to the required altitude.

In conclusion, let us mention the automated remote-control system which is exployed on the Dart missile.

In the remote-control systems considered above, the guidance error is determined and removed by a member of one crew, i.e., the operator. There are instruments, however, which make it possible to automate the process of guiding the missile

to the target to some extent. When the velocity of the missile is about 280 m/sec, it is difficult for the operator to react quickly to a change of the guidance error. Therefore, the guidance system of the Dart is partially automated. Part of the operator's job is executed by instruments. In automated remote-control systems, the measurement of guidance errors, and the shaping of control commands and their transmission to the missile is done automatically, without the participation of an operator. The launch complex of the Dart missile includes a telescopic optical instrument and an electronic computer. Two images are seen in the eyepiece of the optical instrument, which is directed on the target: the target image and the missile image. The operator's only function is to match up these two images. Everything else (determination of the magnitude and direction of the missile's deviation from the target, determination of the necessary command, and so forth) is executed by the electronic computer.

<u>Self-contained guidance system</u>. This guidance system is characterized by the fact that the control equipment is entirely concentrated in the missile itself and, independently without the participation of an operator during the entire time of missile flight, it corrects the missile's motion in the direction to the target. This guidance system program only requires the preliminary installation of the missile flight before it is launched, which is executed by the operator. At present, a self-contained guidance system is used in only one foreign army antitank guided rocket, the 9-BÉBÉ. There is no information on the construction of the guidance system of this missile in the press. Therefore, we can discuss in general terms the principle of arrangement of these guidance systems which are employed abroad for missiles of other classes.

The programmed trajectory of a self-contained guided missile is a straight line. If the missile flies exactly on the programmed line, which connects the launch point and the predicted point, it will hit the target (under the condition that the predicted point is determined correctly). However, during flight, the missile can deviate from the programmed trajectory due to various reasons (for instance, gusts of wind). The function of the self-contained guidance system is to change this deviation and, in accordance with its magnitude and sign, send a command to controls in order to return the missile to the programmed trajectory. As we already know, the controls are the aerodynamic or gas-dynamic rudders. Deflection of the rudders will bring about the appearance of a control force which will also return the missile to the programmed trajectory.

Thus, the self-contained guidance system should hold the missile on the programmed trajectory without the help of an operator. The functions of the operator in a self-contained guidance system must be executed by instruments (measurement of the deviation of the missile from the command post-target line and sending of the appropriate commands).

Let us see which instruments must be included in a simple self-contained guidance system. First, it is necessary to measure the missile's deviation from the programmed trajectory. This requires the appropriate devices. Instruments that are intended for the measurement of any parameter are called meters. Consequently, there must be meters in a self-contained guidance system. Secondly, the measured magnitude and sign of the missile's deviation must be converted into controlling electrical quantities (voltage, current, and so forth). Consequently, there must be converters in a self-contained guidance system. Finally, the controlling electrical quantity again should be converted in some device so that the controls can execute the command. The control-surface actuators serve for this purpose.

The meters in self-contained systems can be gyroscopes, which make it possible to measure the angle of deviation of the missile's axis from the programmed trajectory. A gyroscope that is for this purpose is mounted in such a manner so that the axis of its rotor is directed along the axis of the missile. The deviations of the axis of the missile from the axis of the gyroscope are converted by means of special pickoffs into electrical signals that are proportional to the angle of deviation. These signals are sent to the control-surface actuators which deflect the controls at the required angle. When the controls are deflected, there appears an aerodynamic moment which revolves the missile until its axis again coincides with the axis of the gyroscope. The angle of deflection of the controls will then be proportional to the controlling signal. The magnitude of the latter is proportional to the angle of deviation of the missile's axis from the programmed line or, which is the same, from the gyroscope's axis.

When the direction of the missile's axis again coincides with the direction of the gyroscope's axis, the controlling signal will disappear, the controls will again occupy a neutral position, and, due to this, the aerodynamic moment revolving the missile will disappear. However, the missile will pass by the given position due to inertia, since it cannot stop instantly. This will lead to the fact that the

axis of the missile will again deviate, but in the opposite direction. In this case it is said that there is a negative mismatch angle. Due to this, the controls will turn in the opposite direction. The missile also will again return to the given position under the action of the appearing aerodynamic moment. Due to the action of inertia, it again will pass the position. This process is repeated several times, i.e., the axis of the missile will oscillate relative to the assigned position.

For faster termination of the oscillations, the controls are given an additional angle of deflection that is proportional to the angular velocity of the missile. In this case there will be an increase of the so-called aerodynamic damping moment, upon which depends the character of the oscillations of the missile's axis. The aerodynamic damping moment is caused by the rotation of the missile around its center of mass, and it is greater, the faster the oscillations of the missile's axis are damped. This moment is proportional to the angular velocity of rotation of the missile and is directed opposite the rotation.

A meter is required for measuring the angular velocity of rotation of the missile. The meter may be a rate gyroscope, the signal from which will be algebraically added to the signal from the angular-deflection meter. As a result, just before the missile returns to the assigned position, the total signal will be equal to zero, and the control surfaces will occupy the neutral position. Upon further motion of the missile, the control surfaces will deflect by means of inertia in the opposite direction, an aerodynamic moment which will prevent the inertial motion of the missile will be created, and the missile will smoothly approach the assigned position. The principle of operation of a simple self-contained guidance system can be found from a consideration of Fig. 28, which shows a block diagram of a self-contained control system. The advantage of a self-contained guidance system is its complete noise immunity. If the enemy somehow could still influence the flight of a missile in a remote-control system, he could not do it with this type of guidance system. Now we shall discuss some proposed guidance systems of antitank guided missiles.

Several countries have recently published reports on projects for the creation of homing ATGM's. These reports tell of the creation of ATGM's which must be equipped with homing guidance systems. In particular, the United States is developing two types of homing ATGM's: the Tomahawk and the Shillelagh.

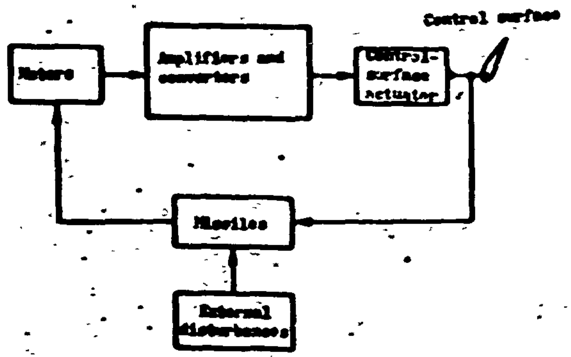

Fig. 28. Block diagram of a self-contained control system.

To this time, this type of guidance system had been used for air-to-air and surface-to-air missiles. The principle of operation of homing guidance systems is well-known. Therefore, we shall discuss in a very general sense, based on the data of foreign press concerning air-to-air and surface-to-air rockets.

The main distinction of a homing guidance system from the considered systems of remote control and self-contained guidance consists in the fact that the missile as if guides its own flight.

A remote-controlled missile is guided at a distance by an operator. A missile with a self-contained guidance system flies on a preset trajectory. The function of its guidance system is to keep the missile on this trajectory. The tasks of the homing guidance system are to estimate the position of the missile with respect to the target and to generate control commands which would make the missile hit the target. During the flight of a homing missile, it is always controlled, not by an operator, but by an instrument that is located on board.

A homing guidance system can be applied in combination with other guidance systems, for instance with a remote-control system. In this case the missile is guided by means of the remote-control system by the operator to a distance close to the target, after which the homing guidance system is actuated. This type of guidance system is said to be combined.

The action of homing guidance systems is based on target contrast. Many targets, including tanks, are isolated on the surrounding background by a number of criteria, i.e., they possess the property of contrast. They can reflect or emit electromagnetic energy.

In those classes of rockets in which homing guidance systems are now being employed, waves of the visible, infrared, and radio ranges are used. The Americans are trying to use ultraviolet and infrared rays, which are also called heat rays, in the ATGM homing guidance system. Infrared rays are emitted by targets that have heated components, for instance the exhausted pipes of engines. Furthermore, these rays are emitted by jet aircraft, ships, thermal electric power stations, blast furnaces, factory smokestacks, etc. The greater the amount of infrared rays emitted

by the target, the greater the magnitude of its contrast on the surrounding background. A characteristic of the quantity of emitted or absorbed energy per unit time is the radiant flux, $P = \frac{W}{t}$, where W is the energy emitted, and t is the time of emission.

Radiant flux is measured in watts; it characterizes the emissive power of radiation. The magnitude of radiant flux emitted by any surface of a body is not identical in different directions and depends on the quality of this surface. When infrared rays pass through the atmosphere, they are absorbed by it. Therefore, the concept of a transparent atmosphere was introduced which is characterized by the transmission (transparency) coefficient — the ratio of the quantity of radiant energy entering a given layer of the atmosphere to the quantity of radiant energy leaving a given layer of the atmosphere. If the transmission coefficient is equal to unity, the radiant flux in this case will not be absorbed by the atmosphere. The transmission coefficient also depends on the wave length of the infrared rays. The atmosphere best admits infrared rays with wave lengths of 3.4-4.2 microns, and absolutely does not admit rays with wave lengths of 1.8-1.9, 2.6-2.9, and 5.2-7.5 microns.

Infrared rays are dispersed by fog particles, drops of rain, and dust particles. The greatest amount of dispersion occurs when the wave length of the infrared rays is equal to the radius of the dispersing particles.

The main element of a homing guidance system is the target coordinator, which automatically continuously measures the target position data with respect to the position of the missile in space. A signal in the form of voltage or current is obtained at the target coordinator's output; the mismatch angle that is proportional to it is found between the axis of the coordinator and the missile-target line. When the mismatch angle is equal to zero, the signal at the coordinator's output is also equal to zero. With the appearance of the mismatch angle, there also appears a signal that is proportional to the given angle. In homing guidance systems to use the infrared rays emitted by the target, the target coordinator is called a heat-seeker.

The heat-seeker (Fig. 29) consists of an objective 1, two disks with rasters 2, a condenser, an amplifier, four filters, and a relay block. Its principle of action consists of the following. Infrared rays from heated parts of the target (aircraft, tank, and so forth) strike the plane of the rasters (a raster consists of opaque dashes applied with definite spacing) that are placed on revolving disks (Fig. 30).

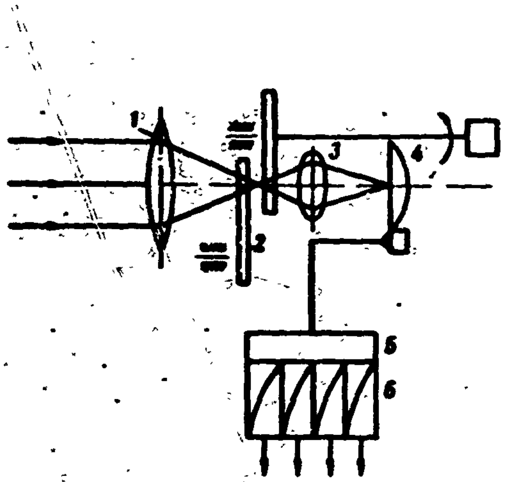

Fig. 29. Diagram of a heat-seek: 1 — objective; 2 — disks with rasters; 3 — condenser; 4 — photocell; 5 — amplifier; 6 — filters.

Fig. 30. Revolving disks: 1 — first raster of disk, up-down; 2 — second raster of disk, up-down; 3 — first raster of disk, right-left; 4 — second raster of disk, right-left; 5 — center of focal plane.

These disks are the main control device of the heat-seeker. One of the disks controls the "Up-Down" motion of the missile, while the second controls the "Right-Left" motion; each disk two rasters apiece. The rasters are arranged in a row, forming opaque segments that alternate with transparent segments. The spacing of all four rasters is different. The disks revolve in opposite directions in such a way that the transparent sector of one disk and the opaque sector (with the dashes) of the second disk simultaneously approach the center of the focal plane.

Depending upon which raster the target image strikes, its radiation will be converted (modulated) by the revolving disks with a different frequency. The appearance of these frequency signals characterizes the deviation of the longitudinal axis of the missile with respect to target to the right, to the left, up, or down. The modulated radiation, after passing through the revolving disks, is collected by the condenser 3 (Fig. 29) and sent to photocell 4. The current of the photocell is amplified in the amplifier 5, whose output has four filters 6, that admit only the voltage which corresponds to the modulation frequencies of the luminous flux of the target. The modulation frequency of this luminous flux corresponds to the direction of deviation of the optical axis of the system from the luminous flux of the target. Each filter in turn is connected to a relay, which controls the operation of the control-surface actuator motors.

If a current of the specified frequency goes from the photocell to the amplifier, the relay of a given filter is actuated, which is tuned to this frequency, and the corresponding motor of the control-surface actuator is operated, which in turn

deflects the corresponding control surface.

If the target projection is exactly on the optical axis, equal voltage of all selected frequencies will proceed to the amplifier, and the control surfaces will remain at rest. In view of the fact that the optical axis of a homing guidance system is combined with (or parallel to) the longitudinal axis of the missile, the latter will strictly follow the direction of the target. If the target again deviates with respect to the optical axis, the projection of its image will deviate, thus causing an inequality of images. This will lead to the triggering of the corresponding control-surface actuators, and the missile will be again directed towards the target.

In simple case under consideration, the process of missile guidance occurs in such a manner so that its axis is always directed towards the object, and the missile flies along a certain curve, which is called the pursuit curve (Fig. 31). When the target makes a flanking movement (as shown in Fig. 31), a characteristic feature of this method of guidance is the fact that the missile always approaches the tail of the target, as a result of which there is obtained a large curvature of the trajectory. In order for the missile to accomplish flight on this trajectory, it must have a large reserve of the aerodynamic forces that appear upon deflection of the control-surfaces. Therefore, such homing missiles in foreign armies have well-developed lifting surfaces.

In order to decrease the curvature of the missile's trajectory, the following method is applied abroad: in each time interval, the missile is not directed to the target, but to a certain point in which the missile should encounter the target. Let us assume that the target is moving uniformly and rectilinearly (Fig. 32), and the axis of the missile at the time of launching is deviated with respect to the missile-target line, $C_0 Ц_0$, at a lead angle ψ with such a calculation so that during rectilinear flight of the missile and the target their encounter would take place at a certain fixed point. In this case, obviously, the time of flight of the missile and the target will be identical; the lead angle ψ is determined by the equation

$$\sin\psi = \frac{V_ц}{V}\sin q,$$

where $V_ц$ is the velocity; V is the velocity of flight of the missile; q is the target course angle.

It follows from this equation that, in the process of guidance, the line that connects the missile and the target will move parallel to its initial direction,

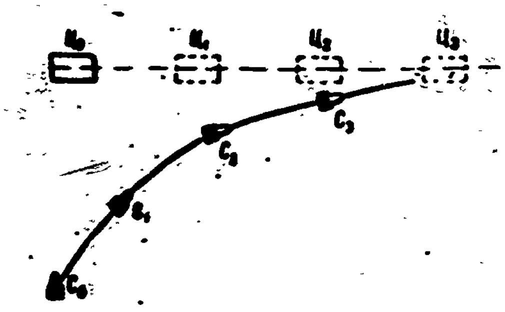

Fig. 31. Pursuit curve.

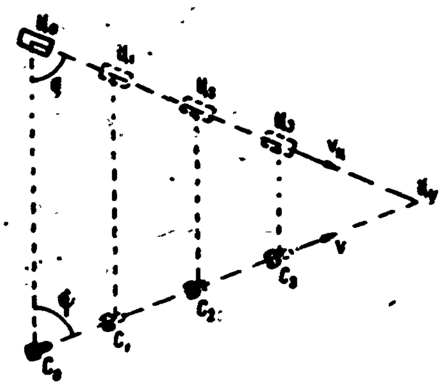

Fig. 32. Firing at a predicted point.

$C_0\text{Ц}_0$. And if a heat-seeker is deployed at the time of launching with respect to the axis of the missile at angle ψ in the direction of the target, control signals will appear at its output only when the axis of the missile deviates from the line $C_0\text{Ц}_0$.

Upon deviation of the axis of the missile from the line $C_0\text{Ц}_0$, the axis of the heat-seeker will deviate from the missile-target line, which will lead to the appearance of a control voltage that is sent to the control-surface actuator. The deflection of the control surfaces causes the body of the missile to turn in such a way as to return the missile to the trajectory that corresponds to its flight to the point of target impact. In this case it is necessary to correct only the trajectory of the missile with respect to the straight line $C_0\text{Ц}_y$, which does not require a large reserve of control forces; this means that the lifting surfaces of the missile (wings) can be made considerably smaller. However, the picture changes when the target maneuvers. When the target changes the direction of its motion, the value of the course angle will change and, so that the missile flies to the predicted point, it will be necessary to change the magnitude of the lead angle. In order to change the course angle during flight, it is necessary to ensure free movement of the heat-seeker with respect to the body of the missile. Therefore, heat-seekers sometimes are positioned in such a manner so that they can move with respect to the body of the missile. Let us assume that the missile has one of these mobile heat-seekers, which ensures continuous target tracking. Then the question arises of how to control the motion of the missile so that angle ψ, which is between the axis of the heat-seeker and the axis of the missile, is always planned in accordance with the equation

$$\sin\psi = \frac{V_{\text{ц}}}{V}\sin q.$$

In order to answer this question, it is sufficient to recall that when guiding a missile to the predicted point of target impact the missile-target line moves parallel to its initial direction, which connects the missile and the target at the time of launching. Consequently, if we construct the lead angle in such a way so that the missile-target line moves forward in the process of guidance, the missile will be guided to the predicted point of target impact. Obviously, it is sufficient to measure the angular velocity of the missile-target line and, in accordance with the change of this velocity, send commands to the control surfaces in order to reduce this angular velocity to zero. This means that the lead angle in this case will be constructed automatically, since the equality to zero of the angular velocity of the missile-target line signifies that it is moving forward and that the missile is being guided to the predicted point of target impact. The design of a tracking heat-seeker is more intricate as compared to a stationary heat-seeker because of the necessity of having a special device for automatic target tracking. Inasmuch as with the use of this guidance method the missile-target line moves parallel to its initial direction, this method is called the parallel approach method.

At present, we know of other guidance methods abroad which offer the possibility of decreasing the curvature of the missile trajectory as compared to the pursuit method. Their essence reduces to the fact the velocity vector of the missile at each moment of time is not directed to the target, but to a certain point that is ahead of the target.

Homing guidance systems can be active, semiactive, and passive.

In an active homing guidance system, the radiant flux is increased by irradiating the target with the form of energy that the target coordinator uses. The source of energy that irradiates the target is placed on the missile.

The target is also irradiated in a semiactive guidance system. However, in this case the source of energy that irradiates the target is located outside the missile (for surface-to-air missiles it is on the ground, and for air-to-air missiles it is on an aircraft). The energy that is reflected from the target goes to the receiver which is located on the missile.

The target is not irradiated in a passive homing guidance system, and the receiver, which is located on the missile, uses the energy that is radiated by the target itself.

American specialists are attempting to apply the semiactive method of homing guidance for ATGM's.

Of special interest is the attempt of American specialists to use the latest achievement of science and technology in ATGM guidance systems, i.e., quantum-mechanical generators (lasers).

The operation of these instruments is based on the property of molecules and atoms of matter to selectively absorb a certain amount of energy from the outside during their irradiation by external irradiators. The instrument passes into an excited state and begins to externally radiate energy, passing again into a state that is stable from the energetic point of view. It is known that atoms and molecules can emit oscillations of strictly defined frequencies. This is explained by the fact that an atom can be in defined energy states. This means that the energy of the atoms, which is determined by their oscillations in a crystal lattice of matter or the energy of electrons revolving around a nucleus, can take only fully defined values. The transition from one energy state to another is accompanied by radiation or absorption of a strictly defined amount of energy. Absorption and emission of light occur with definite portions of energy (energy quanta or photons), and not continuously. The increase of the energy of a particle is called its excitation. A particle can be excited by different methods: heating, electrical discharge, chemical action, and light quanta. The electrons in excited atoms and molecules are on higher energy levels. The possible discrete (discontinuous) energy states of an atom or molecules can be symbolically depicted as the levels E_1, E_2, E_3... (Fig. 33), which are called discrete energy levels. The distances between them are different for different chemical elements, but are identical for all atoms of a given element. The energy of an atom can be changed only by the quantities E_2-E_1, E_3-E_1, etc., i.e., discretely. The transition of an electron from one energy level to another is connected with the emission or absorption of light.

If a particle in the initial state possessed the energy E_m, and E_n in the final state, when $E_n > E_m$ it absorbed a light quantum, and when $E_n < E_m$ it emitted a light quantum that had an energy of $h\nu = E_n - E_m$. In this case ν is the frequency of the emitted or absorbed light quantum, depending on the difference between the initial and final energy levels; h is Planck's constant, which is equal to 6.65×10^{-27} $g \times cm^2 \times sec^{-1}$.

A beam of light with frequency ν, which is radiated by a large quantity of

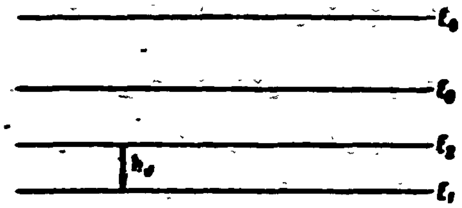

Fig. 33. Energy levels.

identical atoms that accomplish the same jump, will consist of a certain number of quanta, each of which has the energy $h\nu$. The energy of a light beam will be equal to either $1h\nu$, $2h\nu$, $3h\nu$, or $nh\nu$, i.e., it will consist of 1, 2, 3...n light quanta. For the visible portion of the spectrum at $\lambda = 5 \cdot 10^{-5}$ cm and $\nu = 6 \cdot 10^{14}$ 1/sec, the quantum energy is equal to $h\nu = 6.65 \cdot 10^{-27} \cdot 6 \cdot 10^{14} = 4 \cdot 10^{-12}$ erg $= 4 \cdot 10^{-19}$ joules.

A large quantity of various kinds of atoms and molecules occur in nature. They can be on various energy levels. Electromagnetic oscillations of practically any wave length can be obtained with their help. The spontaneous glow of a substance, which is caused by the transition of its excited particles to a lower energy level, is called luminescence.

Particles of a substance can be in an excited state for a longer or shorter length of time. The time that a particle remains in an excited state is called its lifetime, and it varies within wide limits. A medium containing excited particles is called an optically active medium. When the lifetime of a particle in an excited state is great, e.g., from a few seconds to several days, spontaneous glow of the medium appears, i.e., photoluminescence. When the spontaneous glow of the medium is natural, the excited particles enter a lower energy level without external influence. When the lifetime of a particle in excited state is short, e.g., from a millionth to ten-millionths of a second, so-called fluorescence appears. The process of the transition of excited particles to a lower energy state may be accelerated artificially. The luminous intensity of the medium will then simultaneously increase. This requires that the medium be influenced by monochromatic radiation, the frequency of which should coincide with one of the spectral lines. In order to amplify the flux, it is necessary that the particles of the medium have the necessary excess energy which could be radiated, i.e., the particles should be in an excited state.

The particles of a medium can be artificially held on the upper energy level when the medium is "pumped" by the energy from the external source. Inasmuch as the lifetime of a particle in an excited state is short (10^{-6}-10^{-8}) when the energy "pumps" the medium it will be simultaneously radiated, i.e., the phenomenon of fluorescence will occur. If an active material is excited by some method (electric

discharge or pulse tube) to a higher energy level, the energy of an atom of the medium will increase from level E_1 to level E_K. The active medium can be a crystal, a gas, or vapors of various chemical elements or their mixtures. The material of an active medium and the levels are selected so that the lifetime on level E_K is sufficiently long. When this medium, which is in an optically active state, is irradiated, different effects can be obtained. For instance, the excitation energy can be immediately turned into thermal energy without the emission of light; this occurs when the irradiating beam is an infrared ray, i.e., ν_{Ki} corresponds to the energy of the infrared portion of light. When such a photon strikes the active medium, the atoms of the latter transfer to a lower energy level without the emission of light, returning the excess energy to the crystal lattice of the medium.

If ν_{Ki} lies in the region of the visible spectrum, there can occur acceleration of the transition of excitation energy into the energy of visible rays. The medium then flashes brightly and dies out quickly, and the monochromatic beam flux, which strikes the optically active medium, forces an excited atom of the active medium to transfer from the upper energy level E_K to a fully defined intermediate level E_i. In this case, $h\nu_{Ki} = E_K - E_i$. As a result, a new photon will be obtained which corresponds to the spectral line ν_{Ki} that is characteristic for the given medium. This photon will be radiated in exactly the same direction as the striking one, i.e., amplification of light will occur. This is the principle of action of quantum-mechanical amplifiers. If part of the energy in such an amplifier from the output in the corresponding phase is returned back to the input to an optically active medium, it will function as a self-exciting generator. The power of a similar generator will depend on the material selected, the method of its activation, and the power of the "pumping" generator.

The active medium in generators can be synthetic ruby crystals, which consist of a crystal of aluminum oxide with an addition of chromium oxide. The active medium in this case are the chromium ions (the active medium may also be crystals of calcium fluoride with an addition of uranium or samarium).

If a weak beam of red light is introduced into a ruby crystal that is made in the form of a rod, then, upon passage through the crystal, this beam will transfer the chromium ions from the middle level to a lower one. With a single passage through the ruby, an impulse of light will force a small number of atoms to radiate energy. Therefore, the amplification will be small. In order to obtain a large amplification,

it is necessary to force the light impulse to pass through the ruby repeatedly. This is attained with the help of mirrors. The ends of the ruby rod are coated by a thin layer of silver, so that semitransparent mirrors are obtained. In the presence of such mirrors, a certain part of the energy will be reflected from a mirror, returned to ruby rod, and the interaction with the chromium ions will continue. The reflected portion of energy will obtain additional energy from the chromium ions. Instruments that are constructed on this principle are said to be quantum-mechanical, or lasers. A diagram of a simple laser is shown in Fig. 34. The ruby rod is approximately 12 mm long and 5 mm in diameter. Its ends are coated with silver. A spiral flash bulb (the same type that is employed in photography) is screwed into the rod. The bulb is a source of green light, which is necessary for excitation of the chromium atoms (for "pumping" them).

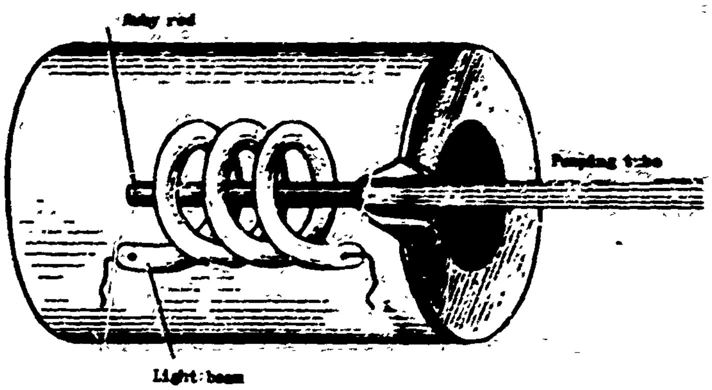

Fig. 34. Diagram of a laser.

When the flash bulb is actuated, an intense parallel beam of red light emerges from the ruby rod; the emissive pulse power of the beam's radiation reaches 10 kilowatts. An instrument of analogous design radiates so much bright light it is possible to see it in daylight at a distance of 40 km. An important property of lasers is the parallel property of the light beam radiated by them. With the help of these instruments it is possible to create a very narrow beam with a huge concentration of energy in it (approximately several megawatts per cm^2) by focusing the beam on an area with dimensions that are approximately equal to the wave length.

The application of lasers in radar has large prospects. Conventional radar equipment, due to their wide antenna radiation pattern, cannot distinguish objects which are close to one another. The high radiation directivity of lasers can correct this deficiency to a considerable extent. American specialists, who attach a large value to ATGM's, decided to use these instruments for guidance systems.

7. ATGM LAUNCHERS

The launching of antitank guided missiles does not require intricate launchers. These missiles can be launched by the most diverse methods: from special launchers, from packing boxes, and finally, directly from the ground. Special launchers are very simple in design. They can be set up on the ground, a motor vehicle, an armored car, a helicopter, or an aircraft.

When a missile is fired from a special launcher, it moves along a guide rail which is given an appropriate angle of elevation.

When missiles are fired from packing boxes that are set up on the ground, the cover, which serves as a support for the front section of the box, is opened, and the angle of elevation thus is obtained (Fig. 35).

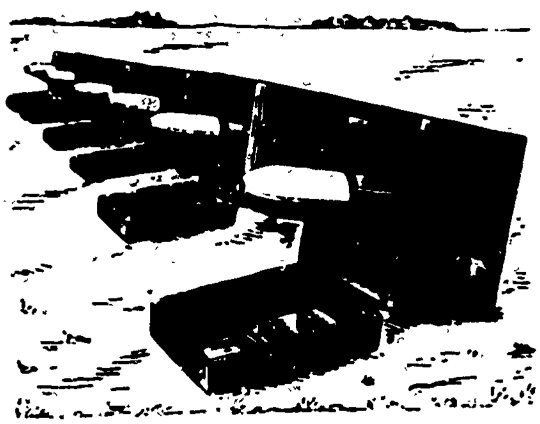

Fig. 35. ATGM's launched from packing boxes (SS-10).

The weight of the launchers is very insignificant as compared to the weight of the antitank weapons; it usually does not exceed 20 to 30 kilograms.

In the case of firing from a motor vehicle, an armored car, a helicopter, or

an aircraft, they also are equipped with guide rails, usually for several missiles (Figs. 36 and 37).

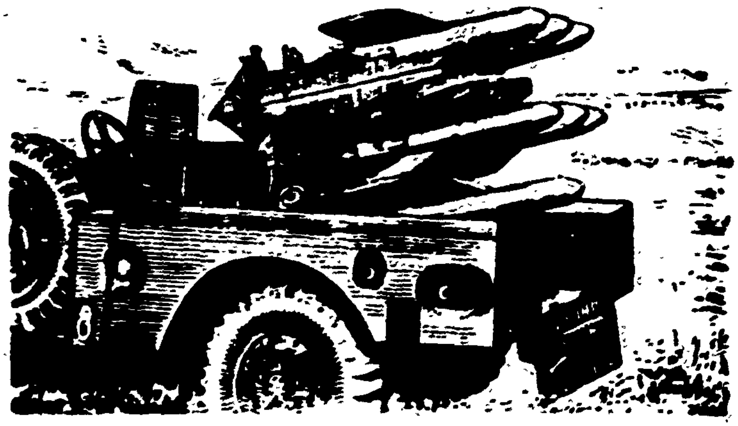

Fig. 36. ATGM's launched from a motor vehicle (SS-11).

Fig. 37. ATGM's launched from a helicopter (SS-10).

Maneuverability is increased significantly when the launcher is used in this way. In the opinion of foreign specialists, this is their important advantage, since the tactical mobility of infantry antitank weapons under the conditions of nuclear war has a large value.

When [ATGM] (ПТУРС) are used on self-propelled vehicles, it is possible to quickly advance a unit of these missiles from the rear and the flanks to the areas under tank attack. ATGM's on self-propelled vehicles can be covered considerably faster from machine gun fire and enemy artillery. To make the ATGM's even more maneuverable, self-propelled devices are presently being developed abroad which will permit all-around fire. In France, for instance, such a device was mounted on the medium tank AMX-13, the revolving turret of which permits ATGM launching in any direction.

Missiles that are launched from the ground do not have guide rails. They are

set up directly on the ground. However, the Mosquito and the SS-11 have rod supports, i.e., spikes, which support the nose cones of these missiles (Fig. 38).

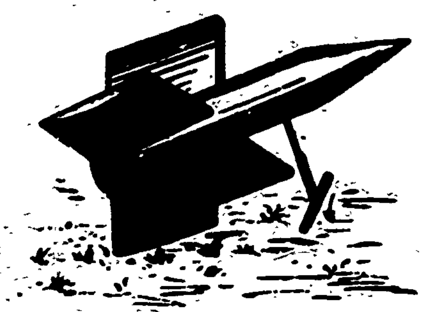

Fig. 38. ATGM launched directly from the ground (Mosquito).

The 9-BÉBÉ missile with self-contained guidance system employs a smooth-bore tube as the launcher (the launcher has a sight).

8. ATGM ARRANGEMENT IN THE FIRING POSITION; FIRING METHODS; AND FIRING INSTRUCTIONS

For combat deployment, as a rule, antitank guided missiles [ATGM] (ПТУРС) are placed in the firing position in batteries, i.e., four to six missiles and more to each battery. The battle order of a battery of remote-controlled Entac missiles is shown in Fig. 39.

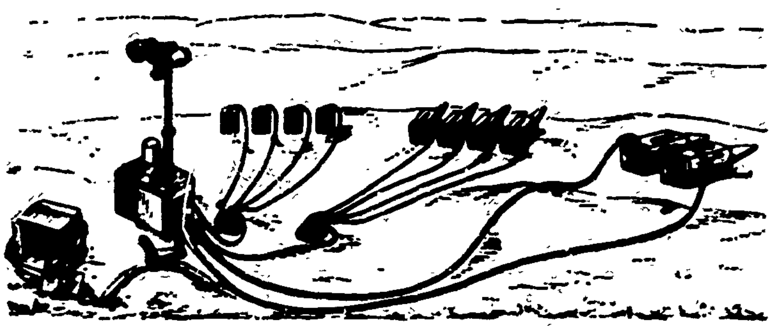

Fig. 39. Diagram of the battle order of an ATGM battery.

The battle order of a battery consists of the firing position and the command post. The command post can be located both in direct proximity to the firing position, and also at a certain distance from it. If the launcher is an armored car or a motor vehicle, the control panel can be placed on the armored car or the motor vehicle.

For firing remote-controlled missiles, the matching method is employed; it is also called the three point method. The essence of this method consists in that the missile is held on the command post (operator)-target line. The operator, who continuously tracks the missile's flight with an optical instrument, always sees it matched with the target. If the missile deviates from the command post-target line, the operator determines the magnitude and direction of the deviation and sends appropriate command signals ("Up," "Down," "Right," "Left,") which return the missile

to the given line. In order to facilitate observation, the missiles are equipped with tracers. In addition, the British missile Pye, for instance, has two periscopes with variable magnification. As the missile gets farther away, the operator changes the magnification of the periscopes from a low magnification to a higher one.

The Dart missile, which has an automated system of remote control, employs the same matching method. The operator only matches the target and missile images; the magnitude and direction of the deviation is determined by a computer; it also sends the necessary commands.

The necessity of visual observation when firing, in the opinion of western specialists, forces special requirements as to the selection of firing positions for ATGM's.

First, the terrain in front of the firing position should be open to the range of guided flight of the missile. Foreign military specialists note this requirement as a deficiency of ATGM's, since it will not always be possible to fulfill it in a combat situation.

Second, the firing positions of ATGM's should be arranged in such a manner so that they are concealed from enemy ground observation. In a combat situation, the enemy can interfere with ATGM firing by laying a smoke screen in front of the position, thus making it impossible for the operators to conduct visual observation of the flight of the missiles. Dust and smoke considerably decrease visibility or can completely close off the sector of fire.

Third, when selecting the firing positions, in the opinion of foreign specialists, one should take into account that dust will form when ATGM's are fired, which gives away the firing position.

Certain foreign ATGM's have devices which eliminate or, in any case, decrease dust-formation when they are launched. For instance, the Mosquito has a special rod support, i.e., spike, which permits the missile to be set up at an angle of 10-20° to the horizon. These missiles can be fired from behind small concealments that are easy to camouflage.

When a battle is being fought in populated areas, foreign specialists recommend that ATGM's be set up directly in buildings and launched from windows for camouflage purposes. Based on data from the foreign press, it is possible to give the following order of occupation of the firing position and the firing order of

antitank guided missiles. The ATGM's are transported to the area of the selected firing position in motor vehicles. Light ATGM's are transported by soldiers from the vehicles to the firing position. Several foreign ATGM's are disassembled to facilitate transporting. The body and nose of these ATGM's are stored and transported separately. They are attached at the firing position. The assembly and installation of these missiles takes from 30 seconds to several minutes, depending upon the design. When the missiles are assembled, the launchers (or containers) are arranged in such a way, so that they can fire in the most tank-endangered direction. Each container is set up in its own specified direction so as to cover a large sector of fire with four to six missiles. The containers with the missiles are set up by the soldiers who transported them to the firing position. At this time, the operator selects the command post, sets up the generator and selector, and deploys the electrical system. He connects the generator, selector, and command instrument to an electric cable. The selector is connected to each missile. After that, the operator inserts spark plugs into the missiles, turns on the guidance system of each missile, and assumes his position at the command instrument.

When enemy tanks appear at a range that is equal to the firing range of the missile, the operator launches the first missile at one of the tanks. In case of a miss, the operator launches a second missile.

Tanks also can be fired upon through areas where friendly troops are deployed. To do this, certain foreign ATGM's have special devices in their control systems which permit the operator to raise the fuse for a certain period of time (when the missile has passed the location of the friendly troops). In certain missiles the fuse is raised automatically for several seconds of flight. Missiles that have similar devices cannot explode when they fall into a friendly troop area.

Foreign military specialists very highly evaluate the accuracy of ATGM firing. They consider that the probability of hitting a tank is 80-90%. This signifies that if tanks are fired upon a sufficiently large number of times, then, out of every 100 missiles launched, 80-90 will hit a tank.

Flight control of an ATGM requires skill and experience. Therefore, several armies have special instruments, i.e., trainers, which simulate missile flight, for training operators (Fig. 40). Trainers are divided into two groups: those for basic training and those for advanced training.

A basic trainer is an electronic device with a cathode-ray tube. The instrument

Fig. 40. Trainer.

also contains a control stick. The screen of the cathode-ray tube has lines of various configuration. These lines simulate the trail of a flying missile. The trainee, by means of the control stick, should follow the lines of a spot of light that is projected on the screen. Instruction on this trainer consists of two phases. In the first phase, the trainees develop manual dexterity. In the second phase, the trainees learn how to track a moving object. For this, in front of the screen of the cathode-ray tube there is placed a target simulator with an area of 10-15 mm^2, which moves at a specified speed. The speed of the target simulator is increased as the trainees acquire more experience.

The trainer for the second period of instruction is more intricate. The trainer utilized for this consists of a panorama screen; films of a moving target and a spot of light are projected on the screen; the trainee matches up the spot with the target by operating a lever on the control panel. An electromechanical computer carries out the connection between the lever movement and the spot on the screen. The same device considers the time of flight of the missile, the delay of the control loop, measures the range to the target, and stops the film after the missile passes this range. The accuracy of guiding the missile to the target is determined the position of the target and the light spot, which are fixed on the screen. The instructor can stop the film and the light spot at any moment and explain the trainee's error to him.

The average duration of operator training (including the combat firing course), which ensures an 80 to 90% target hit is approximately one month.

In the Swiss Army, personnel are trained to fire Mosquito antitank guided missiles by a very simple and economical method. For firing training, a parachute is placed in the missile instead of a warhead. Instruction for firing missile equipped with parachutes is carried out by the following method. A stationary target, i.e., a special target frame (Fig. 41), is fired at. A target hit is scored when the missile flies through the target frame. After the missile flies through the target frame, the operator gives the command "Up." The parachute opens after the missile reaches a certain altitude (Fig. 42). The moment that the parachute

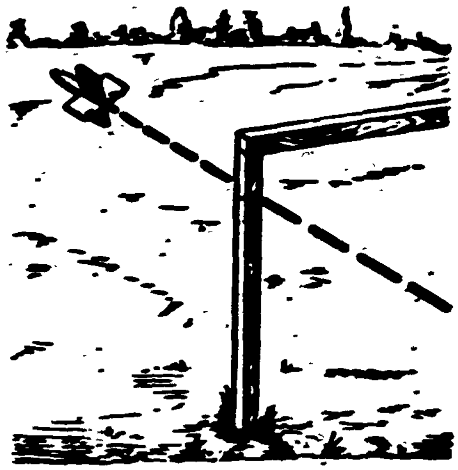

Fig. 41. Target frame for firing ATGM's by trainees.

Fig. 42. Moment of parachute opening during firing training.

is ejected is determined by the operator, who then sends a command to a special device, or this command is generated by a programmed device. With its parachute open, the missile descends smoothly to the ground. Parachutes make it possible to save less than 70% of missiles with on-board electronic equipment and gyroscopes for repeated firings.

9. COMBAT USE OF ATGM's

We have considered the design of antitank guided missiles [ATGM] (ПТУРС) and the methods of firing them above. In this section we shall discuss the following questions: how can ATGM's be used in battle, what position do they occupy in the weapon system of armies, what types of forces can use them, and which units have them?

The rapid development of antitank guided missiles in the postwar years forced the foreign military specialists to think about the possibilities of their combat application. They presently consider that the adoption of ATGM's by the armed forces opens new prospects in antitank warfare and with armored targets in general. Foreign military specialists also consider that the emergence and development of ATGM's will demand a reconsideration of the views on the future of antitank defense and infantry tactics in general, and the tactics of armored forces in particular. However, in spite of the high appraisal of the prospects of ATGM's made by foreign specialists, the question concerning their role and place in contemporary antitank defense and in the weapon system in general has not yet been finally answered. There are very many contradictory statements concerning this question in the foreign press; however, a definite general tendency concerning the combat use of ATGM's has already been noted. It is obvious that the combat application of any new weapons, including ATGM's is based on the maximum use of its positive qualities, taking into account its negative properties, also.

In the opinion of foreign military specialists, as compared to conventional antitank weapons, ATGM's possess a larger range of firing along with a higher accuracy of fire and higher armor-piercing capability. In addition, the operator can be far away from the firing position and well concealed; the weight of ATGM's

is considerably less than weight of contemporary antitank guns. All these positive qualities, in the opinion of foreign specialists, can permit the use of ATGM's in certain cases in both defensive and offensive operations. In the last case, ATGM's that are launched from self-propelled launchers, motor vehicles, and so forth will have the advantage.

Foreign specialists consider that ATGM's can be deployed for reinforcing antitank defense both in the depth of the defense, and also on its forward edge. In last case, the ATGM's will be able to destroy mobile armored targets until their gunfire becomes effective.

By using ATGM's mounted on aircraft and helicopters, it is possible to destroy tanks and other armored vehicles while they are moving and right in the tactical depth of the enemy.

The shortcomings of ATGM's which affect their combat application, in the opinion of foreign military specialists, include, for instance, the presence of a "dead zone" up to 400-600 m deep, which makes it impossible to destroy tanks at close distances. Certain military specialists consider that ATGM's can be applied only for firing on tanks at comparatively long ranges, since upon the sudden appearance of tanks at close distances (to 600-800 m), the operator simply cannot guide a missile to the target.

Another shortcoming of ATGM's, as considered abroad, is their low rate of fire as compared to conventional antitank weapons.

Furthermore, several foreign ATGM's have large dimensions, which hampers their delivery to the firing positions. Therefore, it is considered that the occupation of firing positions and preparation for combat readiness of an ATGM battery requires comparatively more time than required for setting up conventional weapons.

Finally, the shortcomings of ATGM's also include the circumstance that their firing requires the visual observation of an operator. In connection with this, it is considered impossible to employ ATGM's in a number of theaters of operations. Even in the European theater of operations there cannot always be found a more or less even section of terrain that can be seen at a distance of 3-4 km and has no obstacles.

Considering these shortcomings, the foreign military press considers that ATGM's cannot completely replace antitank artillery, and that this new antitank weapon in the present stage of its development can be applied in battle only in

combination with other antitank weapons.

Foreign military specialists consider that antitank missiles can be used by all branches of the armed forces, and furthermore, they can be included in special units of the antitank reserve. In addition, it is considered that arming the infantry with antitank guided missiles will considerably reinforce it in tank warfare in the main types of battle; therefore, ATGM's will be applied most often in infantry units and elements as the official antitank weapons of the infantry. In connection with this, the foreign press has been discussing the question of the organizational structure of ATGM elements, but a final opinion has not yet been made, although the general tendency of organizing ATGM elements in the infantry and motorized infantry units in a number of armies is already clear.

In connection with the fact that the application of weapons of mass destruction has sharply increased the value of small elements, it is assumed that platoons will be armed with antitank guided missiles.

The character of modern warfare is such that it is frequently necessary to quickly change from one form of battle to another. In connection with this, combat elements will make use of maneuver by fire. The structure of the battle order under combat conditions with the application of weapons of mass destruction, in the opinion military specialists, will be such that large intervals will form between strong defense points and support points. This circumstance will also demand maneuvers by companies and platoons which will be able to strike the flanks and rear of the enemy. The element maneuvers will consist of turning and outflanking movements. The sudden appearance of small, well-equipped elements on the flanks or in the rear of the enemy, in the opinion of foreign specialists, can render a decisive influence on the outcome of a battle. Due to this, the mobility and high technical equipment of small elements is given a large value in the foreign military press. It is considered that such elements must have their own ATGM's, since the reinforcement of elements with them in the course of battle by order of senior officers will demand a great deal of time, which is impermissible under conditions of fast-moving battle. For arming small elements, it is recommended to have light ATGM's, which can be transported in shoulder bags. The application of such missiles will make it possible to reinforce the element of surprise in tank warfare.

Recently, several armies of the capitalistic countries were equipped with light ATGM's which can be carried by one man.

The armies of the United States, Great Britain, France, Sweden, and other countries are presently armed with ATGM's.

The United States has armed the antitank platoons of combat-support companies with ATGM's. A typical antitank platoon consists of five squads, each of which has one ATGM launcher, mounted on an armored car. An infantry division has five of these support groups; consequently, it has a total of 25 ATGM launchers. It should be noted that the United States at this time is not producing ATGM's, but purchases them in France and West Germany. The troops stationed in West Germany use SS-10 French missiles, while those in the CONUS and in the Far East use the West German BO-810. Not only units and elements are armed with antitank guided missiles, but also motorized-infantry battalions of armored divisions and brigades.

It is appropriate to note that until recently the United States thought that the best antitank weapons for armored divisions were antitank guns. However, this opinion has sharply changed recently. Inasmuch as it is considered that tanks in modern war will not always advance together with a motorized-infantry armored division, it is necessary to have a large degree of freedom in the antitank respect. The best antitank weapon for motorized infantry under these conditions are ATGM's whose launchers are mounted on armored cars. With this deployment of ATGM's, they will be just as maneuverable as the motorized infantry itself. In connection with this, several studies have been made recently on armored divisions for the purpose of determining a rational means of equipping them with new antitank rocket weapons. The problems of which elements of a motorized infantry battalion should be equipped with ATGM's, how many launchers and missiles should be issued, and how many operators should there be were solved; furthermore, the principles of the combat use of the ATGM's in motorized infantry battalions were worked out. This led to the conclusion that ATGM's should be included in the mortar platoon of each infantry company of a motorized-infantry battalion. The mortar platoon should have an antitank section that consists of two squads, each of which should have one launcher. The launcher crew includes a commander, who simultaneously performs the duties of the operator, a driver, two loaders, and a missile-bearer who must ensure the delivery of the missiles to the firing position and assemble them there. It was decided to arm the motorized-infantry battalions with SS-10 French missiles.

The combat deployment of the antitank sections is directly supervised by the company who gives them their assignments. Antitank sections will be deployed in battle in direct proximity to the forward edge in the battle order of the companies.

It is possible to fire from an armored car, which permits loading inside the vehicle, as well as directly from the ground, depending upon situation and the necessary degree of concealment. In the case of firing from the ground, the operator can select the most convenient position for the command post at a certain distance from the firing position.

In the opinion of foreign specialist, tanks have presently reached the stage in their development when a further increase of their armor protection has lost importance in conjunction with the application of powerful hollow shaped-charge antitank missiles. Therefore, prime attention should be given to arming tanks with sufficiently light and effective weapons. Tanks should have a weight that permits them to be transported by air with the help of aircraft or helicopters. In connection with this, the attention of military specialists is concentrated on rocket weapons in general, and on ATGM's in particular. Specialists of capitalistic countries consider that by arming tanks with ATGM's they can solve the problem of the weight of a tank and its armament, and it will make it possible to have comparatively light tanks that are capable of effective warfare against enemy armored targets with the preservation of the necessary mobility, i.e., in their opinion, the best tank protection from enemy fire. However, many specialists consider that it is still to early to completely replace tank armament with ATGM's, since the latter still have rather large dimensions and it is impossible to place a sufficient quantity of them in a tank. U. S. specialists also consider that it will not be necessary to use expensive ATGM's against all targets. Many targets, such as machine guns and other open weapon emplacements, can be quite effectively destroyed by machine guns or other guns by firing high-explosive shells. Considering all this, it is presently proposed, in addition to ATGM's, to arm tanks with machine guns and light rocket launchers, i.e., to create tanks with combined armament. Such a combination of armament, in the opinion of U. S. military specialists, will make it possible to have sufficiently light-weight maneuvering tanks that possess high firepower and can economically execute various fire missions.

In the foreign press for a long time there was a controversial question concerning which tanks should be armed with ATGM's. It was first considered that only heavy tanks should be armed with ATGM's. It was recently decided to also arm medium tanks with them. As a result of replacing heavy guns with ATGM's, it will be possible to simplify the transportation and supply of ammunition to armored units.

This is also promoted by the assumed decrease in thickness of tank armor due to arming them with ATGM's.

Furthermore, antitank guided missiles have been issued to the antitank platoons of the heavy weapons companies which make up the infantry and motorized-infantry battalions. ATGM's have also been issued to the rocket-fighter antitank companies of the tank battalions of infantry brigades (in this case the personnel and ATGM'S are transported on 16 armored cars that have launchers). A jeep with a trailer transports three SS-10 missiles on the launcher and six on the trailer.

In connection with West Germany's development of the BO-810 ATGM, which is considerably lighter and less expensive than the SS-10, it has been proposed to arm infantry and motorized-infantry platoons with them. However, platoons armed with these ATGM's must have squads that include two operators, motor vehicle drivers, and 16 missiles on launchers (one operator will control eight missiles). The rest of the fire unit will stay in the body of the motor vehicle.

West Germany also uses ATGM's for arming the motorized infantry. They have been adopted as a standard weapon of the motorized infantry battalions of the tank brigades of West German divisions. Each heavy weapons company of tank battalion has an ATGM platoon.

Finally, it has been proposed to start arming tanks with ATGM's. In this respect, the views of the military specialists of the United States and West Germany coincide. The creation of a light tank armed with light-weight ATGM's and capable of carrying a sufficient number of missiles has been noted in West Germany. Launcher in the proposed tank will be placed in a special armored shelter which will be considerably elevated above the tank. Reloading of missiles will be accomplished inside the tank. A special free space behind the projecting part with the launcher is foreseen for the exhaust blast.

The French has introduced ATGM's into the batteries which make up the platoons of infantry companies. A platoon has ATGM batteries which launch the missiles directly from the ground. A battery has six of these launchers. The missiles are transported on a motor vehicle in their packing boxes. A battery also has a command instrument, an optical sight, a generator, a selector, and a monitoring instrument. A regiment contains two infantry companies, i.e., a total of six platoons. Each platoon has six launchers with SS-10 missiles. Consequently, there are 36 launchers in a regiment. Furthermore, ATGM's have been issued to combat platoons of

reconnaissance groups of the composite regiments of the light motorized division. These platoons have their launchers mounted on a light motor vehicle (each motor vehicle holds a complete ATGM battery, i.e., 6 missiles). Each regiment has 60 launchers for SS-10 ATGM's. Regarding the prospects of arming the tanks of the French Army with ATGM's, the views of the French military specialists also coincide with the views of the American and West German specialists. At present, France has a light tank, the AMX-13, which is armed with SS-11 ATGM's.

Work is being conducted simultaneously for decreasing the dimensions ATGM's in order to increase the quantity of missiles in the fire unit of a tank, and also the control system of these ATGM's is being improved.

Thus, it is clear that the capitalistic countries attach a large value to arming tanks with ATGM's. It is first assumed that ATGM's will supplement the artillery armament, and later, as they are improved, they will completely replace artillery armament. Foreign military specialists consider that this replacement will make it possible to decrease the weight of a tank and considerably increase its speed and maneuverability, while retaining its firepower.

Having discussed the questions connected with the position of ATGM's in the weapons systems of contemporary armies and their organizational structure, we shall consider the principles of the combat application of these missiles in the main forms of battle, i.e., offense and defense. In the opinion of the foreign press, ATGM's will mainly be used for reinforcing the antitank defense of units and elements of the infantry in both offensive and defensive operations. We shall analyze the principles of the combat application of ATGM's in these forms of battle according to the present views of the United States Army, where these questions are being given considerable attention.

An offensive operation can be initiated in two cases:

1) when there is direct contact with enemy forces;

2) when the forces preliminarily occupy regions of concentration from which they intend to attack the enemy, who is occupying the defense.

In the first case, combat groups, which contain antitank platoons armed with ATGM's, can attack in one or several directions. If a combat group attacks in one direction, its antitank platoon provides the general support of this group. If, however, a combat group attacks in two or three directions, the antitank platoon can be used for providing antitank defense of the infantry companies of the first

echelon. In other words, the commander of a combat group can use the antitank platoon or part of it for providing the antitank defense of the entire combat group. The commander of a combat group can also assign squads of the platoon to the infantry companies of the first echelon, whereby the first ones to receive these squads will be the infantry companies that have the least amount of tanks or other antitank weap's. Furthermore, when the combat group commander is assigning the antitank platoon squads, he takes into account the number of enemy tanks in direction of attack of the infantry company.

Squads of the antitank platoon also can be assigned to elements that are protecting the flanks of the advancing main forces.

If the attack begins from concentration areas, the combat group forms its battle order, as a rule, in tow columns moving at a distance which would exclude the simultaneous defeat of both columns by a nuclear attack of the enemy. In this battle order of combat groups, the antitank platoon is distributed between the columns. In a column, two or three squads are assigned the elements that are protecting the column movement: one squad can be assigned to the lead infantry company and one or two squads can cover the tail of the column from the attack of enemy tanks from the rear. The remaining squads are used for providing antitank defense of the combat group elements which are moving in the main direction of attack. The mission of these squads of the antitank platoon is to cover the column from a surprise attack of enemy tanks from the flanks and the rear. They execute this mission jointly with the tanks assigned to the combat group.

When an engagement is initiated, the squads of the antitank platoon advanced forward, occupy firing positions, and prepared to repeal the counterattacks of enemy tanks. Elements of light ATGM's occupy their combat position at a distance of 100-250 m from the forward edge during the attack. The infantry companies are continuously supported during the battle by means of the antitank platoon squads alternately changing their firing positions.

When the battle has ended and the infantry companies have dispersed and occupied a defensive position for holding the objective or quickly advance forward, the squads of the antitank platoon follow the orders of the commanders of the infantry companies to which they are attached (if there are no other orders from the commander of the combat group).

A defensive operation is a temporary form of combat. In spite of this, questions

concerning the organization of the defense in general, and the organization of antitank defense in particular, are given a very large value and allotted much attention.

A combat group can set up a defense both within a division, and also apart from its main forces.

In a war without the application of nuclear weapons, the front line of defense of a combat group will be up to 4 km wide in open terrain and up to 2.5 km in rugged terrain. The depth of the defense area in both cases will be up to 3.5 km. The front line of defense of a combat group in a nuclear war will be from 3.5 to 6 km wide. The depth of the defense area in this case will be from 2.5 km to 5 km.

The mission of a combat group in a defensive operation is to stop the enemy before the forward line of defense and to repel an attack; in case of a breakthrough of the defense by the enemy, the combat group should counterattack him and restore the line of defense. A combat group in a defensive operation can be given additional antitank weapons.

The deployment of authorized and attached antitank weapons depends on the size of the defense area of the combat group and its mission. Elements of light ATGM's that are launched from the ground occupy their defensive combat position usually 100 to 250 m from the first line of defense. In case of a wide front of defense and the presence in it of several directions in danger of a tank attack, squads of the antitank platoon are assigned to the infantry companies in these positions. The antitank squads will take their orders directly from the commanders of the infantry companies and will carry out their instructions.

When other antitank weapons are assigned to infantry companies, the ATGM squads occupy firing positions which should ensure mutual fire communication with the other attached antitank weapons (antitank guns, tanks, etc.).

Antitank defense in the American Army is set up taking into account natural obstacles reinforced by engineering constructions. Furthermore, it is supplemented by antitank mine fields, field artillery, and aerial bombing of tanks at the defense approaches. Taking all of this into account, ATGM firing positions are set up in areas under danger of tank attack which are weakly covered by other antitank weapons. In addition, special attention is given to the zone of 100-400 m from the first line of defense (it is in the ATGM "dead zone"). In connection with this, the ATGM fire communication with the other antitank weapons, must be set up well, right up to antitank guns. The fulfillment of this requirement is further dictated

by other consideration. In the opinion of the Americans, the enemy will try to disrupt the use of ATGM's, whose firing, as we already know, requires visual observation. The enemy can employ smoke screens to blind the operators; therefore ATGM firing should be covered by antitank artillery. The firing of the latter does not depend as much on visual observation as ATGM firing. Furthermore, the firing accuracy of antitank artillery is sufficiently high.

If infantry elements are given an insufficient quantity of other antitank weapons for antitank warfare on close approaches to the first line of defense, it is necessary, in the opinion of American specialists, to erect antitank obstacles in front of the ATGM firing positions.

In connection with the above-indicated disadvantage of ATGM's, it is considered that the ATGM firing positions should be set up in open sections of the terrain, but at the same time they should be hidden from the visual ground observation of the enemy. American specialists pay very much attention to the camouflage of ATGM firing positions. They consider that the dust and smoke that forms during firing will give away an ATGM firing position.

When a combat group is occupying a defensive position, the width of whose front does not exceed 4 km, and there is only one direction under danger of tank attack, the antitank platoon is not broken up into squads, but is used intact for covering this direction. In this case the squads of the platoon set up a mutual fire communication between themselves.

ATGM elements may be employed in a defensive operation by the American Army also in the reserve of a senior commander, especially ATGM's on self-propelled launchers.

Military specialists consider that defensive infantry units cannot always successfully repel a tank attack of the enemy in view of the superiority of the attacking forces. In connection with this, antitank weapons may be ordered to the threatened sector of defense in the course of battle. In this case, ATGM's on self-propelled launchers are irreplaceable mobile and powerful antitank weapons, since neither mechanized antitank artillery, nor light ATGM's, carried by soldiers, will be able to accomplish such a rapid maneuver. In the opinion of many western military specialists, ATGM's on self-propelled launchers are powerful highly-maneuverable antitank weapons which successfully combine the impact of an antitack gun, and high maneuverability. These are the only weapons in modern warfare that

can carry out a wide maneuver on the battlefield, rapidly approaching enemy tanks and destroying them with their own fire. For realization ATGM's on self-propelled launchers must occupy firing positions in such areas from where it is possible to quickly move in the threatened tank-endangered direction. These areas, as a rule, should be behind the elements of the first echelon. It should be noted, as American specialists consider, that ATGM's on self-propelled launchers, and high-caliber ATGM's as a rule, are not as good as light ATGM's in the sense of camouflage. Therefore, heavy ATGM's on self-propelled launchers are best employed when they are centralized in the reserve of the senior commander for general support of the infantry elements that compose the first echelon, which cannot repel an enemy tank attack without the assistance of ATGM's.

Now we shall briefly mention the problems of directing ATGM elements in battle.

An antitank platoon can be directed by means of telephone communications, as well as by radio. An antitank platoon has telephone equipment and the necessary quantity of telephone cables to set up telephone communications. The squads also have telephone equipment and cables which can be used for setting up communications with the platoon or infantry company to which they are attached.

The leader of an antitank platoon can also direct the squads by radio, for which the platoon has a radio set that operates in the radio network of the platoon and in the radio network of the combat group. The squads also have their own radio sets. If a squad is attached to an infantry company, its radio sets operate in the radio network of the platoon and in the radio network of the infantry company.

Considerable attention has recently been given abroad to the application of antitank guided missiles in aviation.

The French mounted SS-10 ATGM's on helicopters and successfully used them in their dirty war in Algeria.

The United States and France are presently employing ATGM's not only on helicopters, but also on aircraft that have velocities up to 440 km/hr for destroying tanks, armored cars, and fortifications. For this they use special launchers, while the control equipment remains unchanged.

The SS-11 is employed on the aircraft. In particular, SS-11 missiles are launched from the Potex-75. In this case it should be considered as a flying launcher for rocket missiles. The crew of the Potex-75 consists of a pilot and a gunner (operator).

On the basis of results of tests conducted with ATGM's on helicopters, foreign military specialists came to the conclusion that the launching of ATGM's from helicopters has a large value in the tactical respect. In distinction from an airplane, a helicopter permits a better use of the terrain, although it does not have air superiority. A helicopter, by shifting from concealment to concealment, and from hollow to hollow, can unexpectedly attack moving enemy tanks before they make their attack. A sudden attack can also destroy an equipment depot on the initial line behind the front. In the opinion of foreign military specialists, even a powerfully developed tank offensive may be broken up. Helicopters with SS-10 missiles and aircraft with SS-11 missiles can render direct support to the infantry and armored forces from the air. Helicopters with ATGM's can move with an advancing infantry, give it support by destroying hostile tanks, and they can also accompany a column of tanks, providing it with direct support from the air.

The H-13 helicopter can carry four SS-10 missiles and three crew members, while the VH-1A helicopter can transport up to six SS-10 missiles and, in addition to this, an extra round of ammunition in the cabin, which is designed for five men. Missiles are launched from the VH-1A helicopter by the co-pilot.

Antitank guided missiles may also be used by airborne troops. In this case it will be possible to launch the missiles from special launchers or directly from the ground. The control panel has a distributor for six missiles. The SS-11 missiles, which are intended for use by airborne troops, are equipped with devices for dropping them by parachute together with a container.

10. PERFORMANCE CHARACTERISTICS OF CERTAIN ATGM's

The capitalistic armies have recently developed a large quantity of antitank guided missiles [ATGM] (ПТУРС) that vary in design and performance characteristics, the classification of which was given in the first section of the book.

Contemporary ATGM's have an effective firing range 1-5 km and are able to pierce armor up to 400-500 mm in thickness.

Contemporary ATGM's can be divided into three categories with respect to weight:

— light, which weigh 6-15 kg; their firing range is 1-1.6 km; such missiles include the French 9-BÉBÉ and SS-10, the Swedish Bantam, the Swiss Cobra-I and Cobra-IV, and certain others;

— medium, which weigh 18-20 kg; their firing range is 1.5-5 km; such missiles include, for example, the French SS-11 and Lutin.

— heavy, which weigh 70-140 kg; their firing range is 2-5 km; such missiles include, for example, the Australian Malkara and the Japanese TATM-2.

The speed of an ATGM, as a rule, is equal to 80-190 m/sec. Only the French 9-BÉBÉ has a supersonic speed.

Most ATGM's are equipped with a remote-control system with wire-transmission of commands. The French SS-12 has a remote-control system with radio-transmission of commands, and the 9-BÉBÉ has a self-contained guidance system.

ATGM's are controlled in flight by aerodynamic rudders (for example, the Lutin and the Cobra), by spoilers (SS-10, SS-11, and Entac) or by gas-dynamic rudders (Pye, 9-BÉBÉ).

The wings of most ATGM's are flat and have a cruciform or X-type arrangement.

The Lutin has annular wings.

ATGM's that are employed by infantry and airborne units are launched from the ground from their packing boxes or even without them (the Mosquito and the BO-810). In the last case the missiles are only stored and transported in their containers. The containers have shoulder straps which make them easier to carry.

The variety of performance characteristics of foreign ATGM's can be explained by the absence for a number of years of a single opinion concerning the requirements of an ATGM.

Thus, for instance, the military specialists of such countries as France, Federal Germany, Italy, Switzerland, and Holland considered that ATGM's should be included in the armament of small elements. In accordance with this, these countries developed light ATGM's with a firing range of approximately 1.5 km. The ATGM's are transported and serviced by one man. The United States, conversely, developed a heavy ATGM, the Dart, which was designed not only for destroying tanks, but also for demolishing strong defensive constructions.

The United States recently changed its view on the application of ATGM's. "The Dart" was taken out of production and removed from the armed forces, and the United States Army was armed with French SS-10 light missiles.

The United States is presently developing its own light ATGM's, one of which might be shoulder-launched (the launcher will be similar to an improved version of the bazooka). Furthermore, U.S. military specialists now consider that the destruction of tanks at distances greater than 1.5 km will require medium-weight ATGM's on self-propelled launchers.

The British Army has adopted a heavy ATGM, the Malkara, and also a light ATGM, the Vickers-891, and has purchased light SS-10 missiles from France.

As an example, we shall consider the design of two French ATGM's in greater detail, the SS-10 and the SS-11.

The SS-10 is employed by the French Army and has been adopted by the British, Swedish, Swiss, and West German Armies. SS-10 missiles are also employed on ships of the French Navy.

The design of the SS-10 is that of a miniature airplane, but without a tail section (Fig. 35). Lift is created by the cruciform wings. The missile frame follows the "tailless" aerodynamic configuration. The wings are set at an angle of attack to the axis of the frame; this wing arrangement permits the missile to

turn around its longitudinal axis during flight.

The controls are spoilers which are mounted at the base of the trailing edges of the wings (spoilers in certain foreign sources are called intercepters).

The wings are lifting surfaces with rounded leading and trailling edges. They consist of a skin made from a light alloy with a filter of cork-like wood, e.g., balsa. The wings are attached to the missile body by means of a coupling flange.

Control signals in the horizontal and vertical planes are alternately transmitted through contact rings and brushes to solenoids of opposing pairs of spoilers. The action of each pair of spoilers is reversed at 180°.

The contact rings and brushes are located in a control-signal box which is held in place by a gyroscope.

The gyroscope is accelerated by the gases of a powder charge to a very high speed for 0.1 sec.

The SS-10 has two solid-propellant engines, a booster and a sustainer, with concentrically arranged nozzles. The nozzles of the booster are arranged around the external circumference. The booster accelerates the missile to a speed of 80-90 m/sec in 0.5 sec, which makes it possible to employ launchers without guide rails.

The sustainer ignites when the booster charge burns through the holes in the wall between the series-arranged combustion chambers.

For facilitating missile guidance (when visibility is poor) a tracer is mounted in the tail of the missile, since operation of the sustainer does not ensure good observation of the missile.

The SS-10 is equipped with a remote-control system with wire-transmission of commands. The missile consists of two units: the warhead (first unit); the wings, engine, and body with power supply and control elements (second unit). The warhead is attached to the body by three angular latches with a catch. A dry-cell is inserted before connection; it is intended for supplying power to the spoiler. The units are connected only after insertion of the dry-cell battery.

The warhead of the shaped charge can pierce armor up to 400 mm in thickness.

The fuse is set off by the pressure of the gases of the propellant that is burning in the sustainer, which prevents premature actuation of the fuse.

Both missile units are stored in a strong metal box. The packing holds up well under concussions and shocks.

The missile can be stored for an unlimited period in the box. The battery, which is located in a small external nest of the box, is replaced every six month months. The entire system can function at ambient air temperatures -35° to $+50^{\circ}C$ and is watertight.

The SS-10 usually is launched from its shipping box (packing crate), which contains a small launching platform that is made from tubes. The French Army places the shipping boxes on the ground, while the Navy puts them on ships and even on the gun-carriages of antiaircraft guns of their gunboats, which ensures directional aiming of the missiles. The Americans employ a set of three launchers on a jeep chassis.

A launcher consists of a tubular arch, which supports a short guide rail, and a tube. The arch has an adapter, which connects the cable from the control panel to two wires, and a clip that keeps the wire out of the stream of gases coming from the engine during launching. The wires are steel with enameled insulation. When the missile is rotated, they are twisted into one braid. The wires are coiled navy-style (similar to mooring ropes), since they unwind quickly, thus making it impossible for any kind of revolving bobbin to be employed.

The command-control equipment is designed to provide maximum deployment flexibility under combat conditions. The batteries of the SS-10 occupy tactically important positions. The missiles are connected by means of cables to a junction box which in turn is attached by wires to a device that generates (producer) signals. The equipment also includes a selector and launch-control equipment. This assembly, which usually occupies a concealed position, is manned by one crew member (of a two-man crew); he obtains instructions from the operator, by means of a field telephone or a portable transceiver, for selecting and launching the proper missile of the battery, the firing position of which simultaneously contains four to six missiles.

The operator aims the missile at the target with help of a binocular sight equipped with a reticle or by eye, depending upon the distance and visibility.

The power source of the signal generator is a field storage battery, from which a high-intensity current is supplied to the signal generator.

The launcher, which is mounted on a jeep, is more compact.

The missile can be guided to the target by two methods:

— directly from the jeep (the driver and operator are protected from the

exhaust blast by a protective steel shield);

— from the observation post, where the operator has only the command instrument, while the missile and generator are on the jeep.

In mountainous and wooded terrains, the missiles together with their launchers and control equipment can be removed quickly from the firing position and carried manually.

The SS-10 has a fan-shaped field of fire with horizontal fire at approximately 90°. The maximum range of action is approximately 1.6 km.

In addition to an armor-piercing warhead, an anti-personnel fragmentation warhead may be employed.

The SS-11 (Fig. 36) is not a simple replacement of the SS-10. It was developed specially for mechanized troops, whereas the SS-10 is an infantry weapon. The SS-11 is intended mainly for launching from armored cars, trucks, aircraft, or small ships. It also has another name, the Nord-5210.

The basis of the SS-11 design adopted the guidance system and warhead of the SS-10, and the control system of the supersonic missile Nord-5103 (air-to-air surface).

In the November issue (1958) of Flight there was an article that described the appearance of this missile and made an analogy with the SS-10 and the Nord-5103.

The ogival nose cone, which contains the charge, is screwed to the body of the missile in order to eliminate drag of the rapidly operating cranks. The cylindrical corps, to which the wings are mounted, carries the booster and sustainer. Behind the engines there is a cylindrical compartment that contains the control instruments, two coils of wire, and a tracer for facilitating guidance. The design of the missile body is simple; it is made from a light alloy.

The cruciform wings of this missile possess better aerodynamic characteristics than the wings of the SS-10. Instead of lifting surfaces in the form of flat plates, wings with a symmetric profile are employed. There are no exact data on the material of the wings. They are evidently made from thin sheet material, e.g., a light alloy with a cork-type filler. The wings are set at a certain angle to the axis of the missile body so that the missile revolves slowly in flight. The wire are wound into one strand just as in the SS-10. Turning of the missile in flight neutralizes the various errors in the manufacture of the missile, makes it possible to increase its manufacturing allowances, and thereby to considerably decrease its cost.

The booster is equipped with two lateral jet nozzles whose angle of inclination ensures passage of the nozzle axes through the center of gravity of the missile.

The missile is controlled by deflecting the jet stream of gases.

The mentioned article (from Flight) indicates that this missile-control system must have two opposing pairs of spoilers. It was noted that the spoilers are actuated by two pairs of electromagnets that are excited by a weak current from dry-cell batteries. Thus, just as in the SS-10, the current from the dry-cell batteries must be transmitted by the solenoids of the spoilers in accordance with the signals that are transmitted by two relays and a distributor. One relay is in the missile-control channel in the horizontal plane, and the second is in the vertical plane. The distributor works together with a gyroscope, which retains it in a fixed position. Both relays and the gyroscope-distributor unit, in the opinion of the author of the mentioned article, must be located in back of the engines in a cylindrical housing made from a light alloy. The gyroscope is rotated by a solid-propellant engine.

The two wire coils, through which commands are transmitted to the missile, project on both sides of the missile's tail section at an angle of 90° with respect to the plane of the two booster nozzles. The coils do not revolve, the wire in them is coiled. Two tracers and a launching squib are mounted in the rear compartment, the center of which has an opening for the passage of the jet stream from the sustainer.

The missile is guided to the target by means of a sight of the same type as the one employed for aiming the SS-10. The same power sources, signal generator, and actuator of the remote-control lever are used.

The launchers are made from a light alloy. The missile is suspended by means of a V-shaped attachment or is held on a guide rail by its own weight. Furthermore, the missiles can be launched from their shipping boxes. The missile is stored separately from the warhead. The dry-cell battery, which has a limited service life, is stored in a separate section of the box; it may be replaced without opening the main container.

Launching of the SS-11 is very simple. The missile usually is placed on the trailing edges of its wings, and its nose cone is supported by a strut to give it the appropriate angle of elevation. The upper part of the wooden box is equipped with a tubular rotary strut and a guide for retention of the wires.

The equipment that goes into the SS-11 includes a launch-control monitoring panel (for checking all operations of the guidance instruments) and a device for testing the dry-cell batteries, which are in the missile or stored in containers.

After the launch signal is given, the gyroscope starts to revolve and the booster charge ignites in the two lateral nozzles. The booster accelerates the missile to a speed of 100-110 m/sec in 1.4 sec. The sustainer begins operation 0.7 sec after the booster is launched and continues to accelerate the missile. A terminal design velocity of approximately 190 m/sec is attained for a maximum range of flight equal to approximately 3.5 km after 23 seconds of flight.

When the SS-11 is launched from an aircraft or a helicopter, its maximum speed is limited to 110 m/sec, which is connected with the strength of the wires of communication line.

The lateral range of the missile amounts to approximately 60° in each direction from the launching direction. Deviations from the course can amount to 15-20° during the first two seconds of flight. The minimum range of effective fire is approximately 500 m.

The warhead consists of hollow-shaped and fragmentation charges. It can penetrate 500 mm of armored plate at a target-impact angle of 90°.

The SS-11 is a mass-produced weapons. In the last two years, approximately 5,000 of these missiles were manufactured. The French Armed Forces have several standard launchers for firing the SS-11. Inasmuch as the span of the sweptback wings of the SS-11 is only 2/3 of the wingspan of the SS-10, the vehicle can carry more SS-11 missiles than SS-10 missiles. Airplane manufacturers built-in include launchers under each wing of the Dassault Flamand and the Vought Corsair. Double built-in units are also installed on the cross beam of the Sud-Aviation Alouette helicopter and an original unit is installed on a U.S. Navy Sikorsky helicopter. An airborne launcher is basically the same as a ground launcher, except that it has a light-weight fairing, the missile is always suspended.

The SS-11 is also being tested as a shore-defense missile. It can be easily concealed in shore cliffs and shrubs. The SS-11 is tested in the same way as a weapon that is launched from an LST. The NATO countries, which have long shore lines, show a special interest in the SS-11 since it is easier to conceal and deploy in a combat formation than a gun that has a shell of the same power.

The designation of the SS-11 and the SS-10 comes from the French words

"sol-sol," which means "ground-to-ground."

The length of the missile is 1080 mm, wingspan 475 mm, caliber 165 mm, launching weight 28 kg, weight of warhead 6 kg, maximum speed 190 m/sec, and maximum range 3.5 km.

The dimensions of the shipping box are 89 x 43 x 59 cm, and the weight of this box is 35 kg.

Much work is being conducted abroad on the improvement of ATGM control systems. The remote-control system with wire-transmission of commands is distinguished by its simplicity and noise immunity for light missiles with a firing range of approximately 1.5 km. For medium-weight ATGM's with a firing range of 3-4 km, a remote-control system is being developed with radio-transmission of commands. The control systems of light ATGM's is also being improved. For instance, attempts are being made to develop self-guided missiles. The homing heads of these missiles are being designed with the use of infrared and ultraviolet rays. Furthermore, attempts to create laser-guided ATGM's are being made.

Light ATGM's are presently being developed to have a minimum time for launch preparation. As indicated earlier, the Swiss-developed ATGM, the Mosquito, requires 30-40 seconds for launch preparation, and a total of 4-5 minutes for preparation of an entire battery of these missiles.

Work now is also being done abroad on increasing the armor-piercing capability of ATGM's, increasing their effective range of fire, improving their attitude-control systems, and decreasing the chassis dimensions for their launchers.

Finally, considerable attention is being given to decreasing the "dead zone" in front of ATGM firing positions. In connection with the presence of the ATGM's "dead zone," certain foreign countries consider that the infantry needs antitank weapons that are less cumbersome than ATGM's, but at the same time, sufficiently powerful, i.e., an infantryman should carry this weapon and independently use it for destroying tanks at a distance to 400-600 m. These infantry weapons should supplement the ATGM's, but not replace them. In connection with this, several countries are developing a light infantry antitank unguided weapon for striking tanks at short ranges. For instance, the Federal German Army is adopting a new "Faustpatrone" (rocket grenade) whose firing range, armor-piercing ability, and simplicity of handling make it considerably superior to its World War II predecessor.

The principle of action and design of unguided antitank rocket weapons will be covered in the following section.

11. UNGUIDED ANTITANK ROCKET WEAPONS

The contemporary unguided antitank rocket weapon is a means of infantry defense and is used for the destruction of tanks at close distances. This weapon is very simple in design and handling, and weighs very little. It consists basically of an antitank rocket with a shaped-charge warhead and a tube that serves as a launcher. It has a solid-propellant engine. The weapon can be carried by one soldier, who prepares it for action and uses to destroy tanks. However, there are heavier models that require several men to handle them. They are fired, depending upon the particular model, from the prone, kneeling, or standing position. For aiming the tube, i.e., the launcher, there is usually a simple sight. The shaped-charge warhead makes it possible to penetrate the armor of contemporary tanks at low velocities.

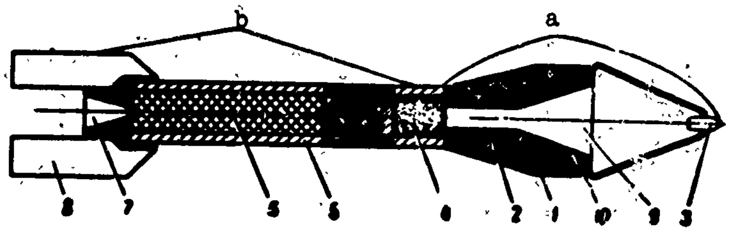

Fig. 43. Diagram of an unguided antitank rocket: a) nose section; b) rocket section; 1 — housing; 2 — payload; 3 — fuse; 4 — detonator; 5 — combustion chamber; 6 — powder charge; 7 — nozzle; 8 — fin; 9 — recess; 10 — metal funnel.

A diagram of an unguided antitank rocket is shown in Fig. 43. As can be seen from the figure, the rocket consists of a nose section a and a rocket section b.

The nose section a consists of a housing 1, an explosive shaped charge 2 with shaped-charge recess 9 and metal funnel 10, a fuse 3, and a detonator 4.

The rocket section 6 consists of a powder charge 6, which propels the rocket engine, an engine chamber 5 (which houses the powder charge and burns it), a nozzle 7, and a fin 8.

An example of a light-weight unguided antitank weapon is the recently developed antitank rocket launcher LAW-XM72 (Fig. 44a and b). It consists of a light single-shot launcher and a rocket grenade. The weight of the grenade and launcher is 2 kg. The launching tube is made of polyester plastic reinforced with fiberglass. The launching tube is also the packing container of the grenade. The diameter of the tube is 75 mm and the length of the packing container is 635 mm. An additional section ispulled out of the tube before firing, so that the packing container can be used as a launcher. The length of the tube in its extended position is 965 mm. The rocket launcher is lined up on the target by means of a peep sight through the rifleman looks, and a transparent graduated plastic bar over the end of the muzzle. Its firing range is unknown. The sight is marked off to 274 m.

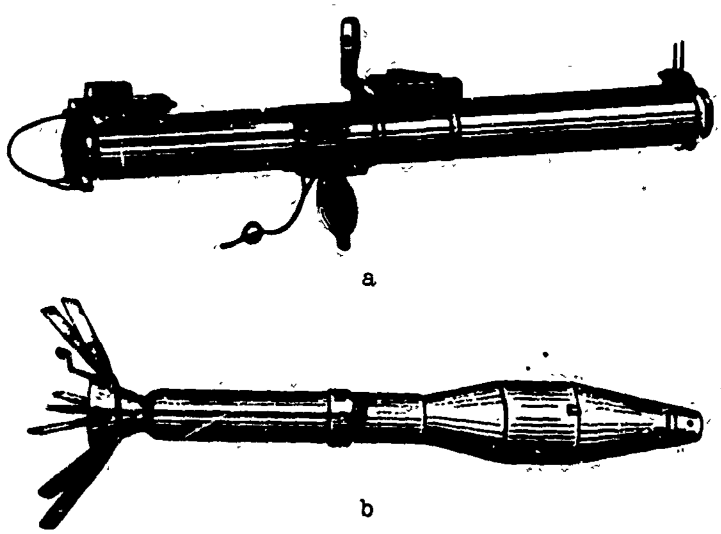

Fig. 44. Contemporary unguided antitank rocket launcher: a) barrel; b) rocket grenade.

The rocket motor of the grenade is completely active in the launching tube until the grenade leaves it. The warhead is equipped with a new powerful explosive, "octol," which was specially developed for this weapon.

The grenade is stabilized in flight by magnesium-alloy fins.

One soldier can carry four of these antitank weapons together with their grenades in a sling over his shoulder. Each tube is equipped with a shoulder strap.

In addition to its prime mission, i.e., knocking out tanks, this weapon also

can be used for the destruction of light fortifications.

A heavier unguided antitank weapon is the American M-20 Bazooka (Fig. 45). The Americans used this weapon in the Korean War for destroying tanks. The Bazooka is intended for use not only against tanks, but also against self-propelled artillery vehicles and armored cars. It is designed also for firing through gun ports of reinforced emplacements and pillboxes.

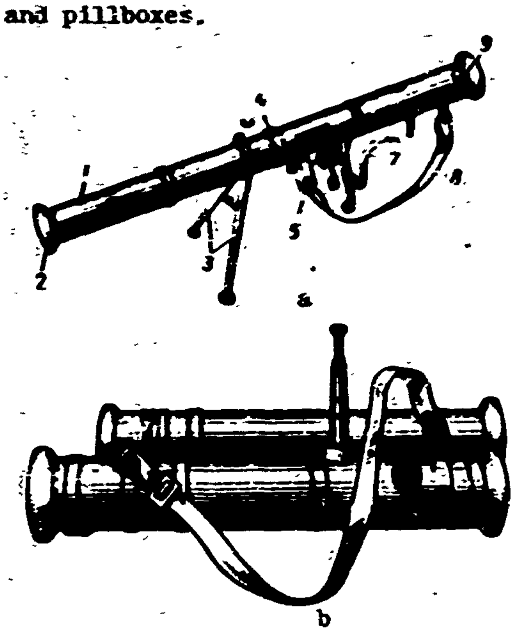

Fig. 45. Bazooka antitank weapon; a) in firing position; b) in carrying position; 1 — barrel; 2 — shield; 3 — bipod; 4 — coupling; 5 — firing mechanism; 6 — sight; 7 — shoulder stock; 8 — strap; 9 — shield.

The folding legs 3 supports the weapon when firing in the prone position. They are folded under the tube for firing in the standing position. The tube is sectional, which makes it easier to carry. It consists of two sections (muzzle and breech). To set up the weapon in the firing position, both sections of the tube are connected to form one piece with the help of a coupling 4 and a split lock. Shield 2 protects the gun crew from the effect of the gases that form when firing. The firing mechanism 5 consists of a magneto, trigger mechanism, and safety switch. A shot is fired by squeezing the trigger.

The Bazooka is fired by direct aiming through the optical sight from the prone and kneeling positions. The crew consists of two men: a loader and a gunner.

The greatest effective firing range for moving and stationary targets is up to 200 m; the armor-piercing ability is up to 280 mm.

The Korean War revealed some serious deficiencies of this weapon: large fire dispersion, low rate of fire, and insufficient effectiveness of fire.

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